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POSSIBLE SOURCES OF POTASH IN AMERICA.*

BY

FRANK K. CAMERON, Ph.D.,
Member of the Institute.

INTRODUCTION.

THE absolute value of the potash market in the United States under normal conditions is relatively small, when compared with that of many other products, being in the neighborhood of $12,000,000. Its importance is very great, nevertheless, for potassium salts are almost a necessity in the production of some of our crops, and are desirable in the production of practically all of them. There are other than agricultural uses where the consumption is much smaller, but where the necessity is even more pronounced, as in the production of certain types of soap and certain kinds of glass. Normally this country obtains about a million dollars' worth of potassium nitrate, nearly all of which comes originally from India, although not always directly. Practically all of this potassium nitrate is used in making fireworks and certain types of powder.

As matters stood before the present European conflict, the consumption of potassium salts for military explosives was insignificant. But it is one of the surprises of the war, even to chemists who are not also experts in military matters, that the

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conflict has brought about such a tremendous demand for types of munitions in which potassium seems to be a necessary constituent, for which there appears to be no satisfactory substitute. Aside from potassium nitrate, as all the world now knows, the whole world's supply of potassium salts came from Germany, from the famous Stassfurt region and from the less well-known Alsatian deposits of rapidly-increasing commercial importance.

The controversies of the year 1909–10 between American importers, the German Kali Syndicate (a selling agency under Imperial supervision), and certain independent producers in Germany led to diplomatic exchanges between the Government of the United States and the German Imperial Government which served at least one good purpose in focussing attention in this country upon the desirability of developing native sources, a desirability confirmed and made more insistent by the unhappy predicament now confronting us. Governmental investigations have been actively in progress since and private initiative has been greatly stimulated. As a result, it has been shown that there are a large number of possible sources of soluble potash salts within the United States, some of which are quite valuable possibly to particular owners, and three and possibly four are potentially possible sources of large commercial importance. At the present writing there is a very small amount of potash salts on hand. The munition manufacturers have been and are still buying eagerly. They prefer the chloride to the sulphate, which is interesting for at least two reasons: it gives a clue to what they are doing with the potash, and it has brought the price of potash, unit for unit, to a higher price in the chloride, though normally the reverse is the case, the sulphate being more highly valued for fertilizers and the chemical industries generally.

No one seems to have any idea, even approximately, as to the aggregate amount of potash salts now in the hands of fertilizer manufacturers and brokers. But it is very clear that the rapidly diminishing imports have about reached the vanishing point, although the world has been scoured for existing stocks, and purchasers for the United States have been as far as Batavia, Borneo. From very recent events it is rather convincingly evident that the embargo on supplies from Germany is not to be lifted until the end of the war. From this point about everything one can say about potash salts is highly speculative. It

seems reasonable to expect that prices will be much higher after the war than before, unless workable sources are developed outside of Germany, for potash salts form one of that country's resources that can and probably will be made to shoulder a very large part of the war's expenses. For this reason the ultimate ownership of the Alsatian deposits is of particular interest to the world at large. The Galician and Spanish deposits, as well as those reported from Peru, are possibly of importance, but the information concerning them that is now available offers very slim hopes.

In so far as the technical features are concerned, it has been demonstrated that the United States can produce far more than its own needs in potash salts. Undoubtedly the technology is susceptible of improvement, and of possibly very great improvement. But the potash can be produced, and the real difficulties in the way of a realization of potash production in the United States are purely commercial and not physical.

FELDSPAR.

Of the several possible sources, attention naturally is commanded first by the potassium silicates, such as orthoclase, muscovite, sericite, or lencite, of which large deposits exist in many regions of the country carrying ten per cent. or more of potash (K_2O). There are probably a hundred patented processes for the extraction of potash from such materials, all of which processes fall into two classes. In the first class the spar, or other silicate, is mixed with coal or coke, lime, calcium chloride, sodium chloride, nitre coke, or some combination of these substances, and heated to form a sinter, from which the potash salt is leached. To evaporate the leachings another supply of heat is required, and the final product is never the pure potassium salt, but a mixture with other less desirable substances. To recover all the potassium salt in a pure state by crystallization methods alone is impossible, and to recover it by further chemical manipulations is prohibited by the cost. To meet these objections, the second class of processes has been devised in which the original mix is heated to melting, and thus the potassium is volatilized either as the oxide or as the chloride. Some of the proposed methods have now been tested on a sufficiently large scale to demonstrate their practicability, so far as the physical

factors are concerned, and one of them has actually produced a few tons of potassium chloride and oxide.

It is claimed by promoters of these processes that there are known large deposits of spar or other potash silicates which can be worked on the steam-shovel plan and which will yield "run of the mine" material containing ten per cent. or more potash at a low working cost. Usually these costs of producing the raw material have been stated to be in the neighborhood of $1.50 per ton. These claims may, in some cases, be valid, but it is difficult to find a disinterested authority who thinks that there is a deposit from which ten per cent. potash spar can be obtained on a commercial scale without hand cobbing. This would make the cost of production prohibitive, and apparently no disinterested investigator considers it practicable to work a product that approximates ten per cent. or more potash. But, in all fairness to the promoters of potash from feldspar, it should be said that the case is not a proved one, either for or against them, in this regard at least.

Again, every disinterested investigator seems to be convinced that potash from feldspar or other silicate mineral is commercially impossible under normal conditions of the market unless the by-product or residue is salable. So far there seems to be but one practical suggestion: to utilize the residue in making cement. Apparently very good cements can thus be prepared, in some cases cements of very desirable special qualifications. But the cement industry is a large one, worth many times the potash industry. It has grown very rapidly and is now standardized. Practically all cement is now sold under standard specifications, which are not met by the feldspar cements without reference to their intrinsic merits. The cement manufacturers, therefore, are not and can not be expected to be willing to remodel their plants, retrain their operatives, secure, if that be possible, a source of spar, and reëducate the buying public, thus risking the larger and sure business on the chance only of securing a much smaller one.

Certainly one, and, if newspaper reports can be trusted, several cement plants are now actually recovering and marketing flue dust containing a relatively high percentage of water-soluble potash. At the abnormally high prices which the product now commands such flue dust can profitably be collected and prove a

godsend to certain consumers of potash salts, as, for instance, the manufacturers of liquid soaps. It is very doubtful if these dusts could maintain a market under normal trade conditions.

DESERT BASINS.

All desert basins, speaking generally, contain considerable stores of water-soluble potassium salts, but usually so mixed with insoluble fill derived from the rim rock as to be quite impossible as commercial sources. A very large number of the desert basins have now been explored more or less thoroughly, and, with one exception, it can now be said that the chance of finding a segregated deposit of potassium salts capable of being exploited commercially is a "miner's chance" only, and a poor one at that. Searle's Lake, in San Bernardino County, California, is, in the ordinary weathers of the desert, a mud flat, but below the surface the solid material is mixed with a brine carrying five or six per cent. potash in the form of the chloride, mainly. But there are large percentages of other soluble substances present—sulphates, carbonates, and borates, as well as chlorides of sodium and magnesium as well as of potassium. It is impossible, by crystallization methods alone, to recover all the potassium from such a brine in anything approximating a pure salt or a mixture of potassium salts only, and the expense of other methods of separation would undoubtedly be prohibitive. It is possible that a segregation of the potassium might be accomplished with a partial elimination of other salts. A large expenditure, reported to be upwards of a million and a quarter dollars, has not yet resulted in a commercial production from this source. One crystallization procedure has been tried out on a large scale and abandoned. It is reported that the present occupants of the site, the Trona Company of California, are trying out another process, the essential features of which are a saturation of the brine with carbon dioxide and the freezing out of carbonates and biborates by reducing the temperature of the mother liquor with an ordinary ice-making outfit. The scheme is an ingenious one, but its practicability in the middle of a large desert seems questionable in the absence of fuller details of this company's plans.

Another difficulty menacing the production of potash salts at Searle's is the validity of the titles of the present possessors.

The Trona Company is controlled by a British corporation, the Consolidated Gold Fields of South Africa, and its holding is the largest ever taken over in the United States by any one individual or company, consequently protestants have arisen, and it is claimed that the original patents on which the title rests were obtained fraudulently. Interested parties claim the possibility that the title of the Trona Company will be rejected and the site withdrawn from entry, pending the passage by Congress of a leasing law. Be this as it may, the uncertainty has hampered, and is hampering, the development of the property. It seems to be the best opinion of disinterested investigators that, ultimately, Searle's Lake may be worked as a source of trona (sodium bicarbonate), with borates and potassium salts as by-products. The production of potassium will be relatively small as compared with the country's needs. Opinions differ as to the probable grade of the potassium salt. The present writer thinks it must be a low-grade one.

ALUNITE.

Near Marysvale, Piute County, Utah, there is a large deposit of massive alunite, an insoluble mineral, with the composition of a basic potassium alumino-sulphate. It is quite similar in composition to alum, hence its name. Other occurrences of alunite in the United States are known, but this is the only one where the material occurs in such form and such quantities as to make it a commercially workable proposition. When roasted, sulphur dioxide and sulphur trioxide are volatilized, and, if the residue be leached, either alum or potassium sulphate is extracted, depending primarily upon the temperature of the roasting. The Roman alum, long a commercial product, is thus obtained from Italian alunite, and it has been reported that deposits in Spain, Italy, Australia, and Japan have at times been small producers.

The technical difficulties in producing potassiums from alunite are not serious. But the deposit is located in a forest reserve. The oxides of sulphur, if allowed to escape into the air, may damage vegetation and bring objection from Federal authorities. If condensed and discharged into the streams they will be a menace to fish life, and thus bring objection from State authorities. Sulphuric acid produced in southern Utah

has no obvious market in normal times. Hence what might be an asset in some localities bids fair to be a serious charge on the working of the Utah alunites. The residue, after leaching, is a very fair grade of alumina, and possession of a large source of alumina has long been a fairer vision to the lay chemist than ownership of a gold mine. However, there is but one large purchaser of alumina in the United States, and this purchaser has spent great energy, time, and money in securing to itself the more important deposits of bauxite. Hence it cannot be expected to look with enthusiasm upon the development of another considerable source of alumina. For the Utah operators to undertake themselves to produce aluminum appears to be impracticable, for reasons which need not be discussed here. Other possible uses of the alumina are receiving serious attention, but are as yet of doubtful importance, as a sufficient outlet for the quantity of material for which disposition is desired.

The most serious difficulty affecting the production of potassium sulphate from alunite is the transportation problem incident to the geographical location of the alunite deposit. The sulphate of potassium is the form most favored by agricultural authorities, it is true, and in normal times this is the form of "potash" which should command the readiest and largest market. West of the Mississippi River the citrus region of southern California is the only important market in the United States, and of especial interest because it will not use chlorides, but readily takes a fair amount of the sulphate. Hawaii and Japan are certainly possible markets to be considered. The mountains of Southern Utah are about as unfortunate a location as could well be imagined, since the potassium salt must expect a long rail haul to any important market.

In spite of these difficulties the exploitation of the alunite has been progressing. By far the major part of the material is in the control of two holders. The Mineral Products Company, having close affiliations with one of the largest fertilizer manufacturers in the country, has established a small plant near Marysvale and has recently produced potassium sulphate on a commercial scale. It is too soon, perhaps, to form any definite opinion on the probable success of this venture. The European war has introduced factors which are difficult to evaluate, and,

moreover, the entire output of the venture is in the hands of one purchaser, so that the crucial test of the open market is not available.

The Utah Potash Company, a recently-organized corporation for the working of the alunite deposits on the holdings of the Florence Mining and Milling Company, is maturing plans for a large installation near Marysvale, proposing to work under the Morgan patents, roasting the alunite with lime, whereby a lower temperature can be employed profitably and the escape of the objectionable oxides of sulphur is prevented. The plans of this company are predicated on the experience of copper, gold, and other mining ventures where a low-grade ore worked on a large scale is often very profitable when it is a commercial impossibility on a small operation. In fine, potassium salts have been produced from alunite in the United States, and there is a very good promise that they will continue to be produced from this source, even when they come into competition with the German salts following the close of the war.

Among the considerable number of sea algæ on the Pacific Coast of North and South America occur four species which are peculiar to that coast and which have the power of absorbing from the sea-water exceptionally large quantities of potassium. Of these four algæ, or Giant Kelps, as they are known locally, *Macrocystis pyrifera* is undoubtedly the most important. It reaches its best development south of Point Sur, on the California coast, and north of the Cedros Islands, off the coast of Mexico, where it occurs in large beds or groves from a few acres in extent to fifteen square miles or more. The entire kelp beds along the coast of the United States and Alaska aggregate 400 square miles or more, and could be made to yield annually, under careful harvesting, some six or seven times the normal demands of the United States. The California beds alone could easily produce more than our present normal requirements.

The *Macrocystis* plant, when freshly harvested, contains from three to five per cent. potassium chloride. The oven-dried plant will average probably sixteen per cent. potash (K_2O) in the form of chloride. The dried plant also contains something less than two per cent. nitrogen, and, being fibreless, it goes to pieces in the soil quickly and readily. Pot and garden experiments with dried kelp have shown it to be an excellent

fertilizer as compared with equivalent amounts of the ordinary soluble potassium salt.

Harvesting of kelp on a scale comparable with commercial conditions has now been done by a sufficient number of different investigators to have definitely demonstrated the practicability and low cost of the operation. The cost of drying artificially the harvested product has not been worked out so satisfactorily, but enough has been done to show that it is very probably feasible as a commercial operation when the technology of the operation has been adapted to the peculiar characteristics of the material adaptations which will speedily come with more practice and actual contact with the material. Apparently a modern rotary drier is the type most promising, since the wet kelp, when heated in a furnace where a stirring is not provided, quickly mats down to a sticky mass, from the surface of which potassium chloride may be volatilizing, while at the same time the wet interior is at a temperature quite durable to the hand.

While dried kelp is itself a good fertilizer and seems admirably adapted to use in mixed fertilizers, and can probably be produced at a cost which would insure a good profit on the basis of before-the-war prices, it is possible that kelp ash may be more worthy of consideration for the Eastern market. In this material, naturally, there is no nitrogen, but there is about sixty per cent. potassium chloride, the remainder being mainly sodium chloride. But it is as a source of pure potassium chloride that kelp has the most promising future. The kelp ash contains, when not too severely burnt, very little soluble material other than potassium and sodium chlorides. Theoretical deductions backed by laboratory experiments have shown the feasibility of a separation of true salts by treating a fixed mass of water with easily calculated amounts of the particular ash, at alternate temperatures, whereby there is a practically complete recovery of the potassium chloride in a nearly pure condition. The writer's own observations and studies have convinced him that these giant kelps offer by far the cheapest and most feasible source known for the production of a practically pure potassium chloride in very large quantities.

But while the future of the potassium sulphate from alunite appears with almost a certainty to lie in fertilizers and in a minor degree as a raw material for the production of potassium

carbonate, a pure potassium chloride from kelp would probably find quite different openings. Undoubtedly some of it would be utilized in fertilizers, but mainly it would be used in the production of potassium chlorate. Potassium chlorate is the basis for a type of "permissive" explosive much favored by construction engineers in the West and growing in favor everywhere. It is probable that a big impetus will be given to its use by the favor which it has found in the present war, but it is particularly as a necessary raw material in the production of safety matches that it is desired. This country could, and probably would, soon become the largest producer of safety matches with a satisfactory development of the kelp industry.

It seems desirable here to point out that, while there may be useful by-products from kelp developed some time in the future, there is no great promise of such in sight at the present time. The oft-heralded promise of cheap iodine is purely illusory. The main, practically the only, commercial source of iodine in the world to-day is the mother liquor from the crystallization of Chili saltpetre. But only about one-twelfth of the possible yield of iodine from this source is recovered in peace times, simply because the world's demands are thus fully satisfied, and the cost at which iodine can be produced in Chili would make it impracticable to recover it from the kelp, though there are no serious technical difficulties in so doing.

The *Macrocystis* has a life-history longer than one calendar year. It is probably a perennial. Moreover, harvesting it to a moderate depth appears to produce a stooling effect, causing it to grow more thickly and heavily. As the average length of a full-grown plant is about 100 feet, from 30 to 70 feet of the plant's length is streaming along near the surface with the tide or wind, and a cutting of four to six feet leaves no noticeable effect upon the harvested area. Consequently it seems probable that several cuttings a year can be made without damage to the bed. Indeed, observations on harvested areas indicate a decided improvement in growth is likely to ensue.

The beds all lie within the one marine league limit, hence control of them is vested in the State and not in the Federal Government. There appear to be no State laws applicable. Capital is notoriously timid of competition, and competition, even to the harvesting of the same bed by rival interests, is quite

possible now, legally as well as physically. Moreover, however unfounded the fear may be, there has been a very real fear on the part of capital, in the absence of any pertinent laws, that it might become the victim of unfriendly legislation, and there has been a very real fear of the possibility of trouble from unscrupulous individual legislators. It has been the lack of adequate State legislation that has been, and is yet, the principal bar to the development of a potash-from-kelp industry.

Small amounts of dried kelp, kelp ash, and high-grade potassium chloride have been produced. One operator produced in all something over twenty tons of potassium chloride, but the company was improperly financed, was the victim of improper promoting and wildcat stock-jobbing, and was forced, because of its financial difficulties, to come to a stop just when it had demonstrated its ability to produce a high-grade product at a cost insuring a profit.

SUMMARY.

From the foregoing it appears that there are within the United States large stores of raw materials from which it is possible to obtain ample supplies of potash salts; that the technology of the subject is sufficiently developed to demonstrate the entire practicability of a supply from native sources, so far as physical factors are concerned. We can have "potash" if we really want it and are willing to pay for it. There are, however, serious commercial doubts affecting each of the four possible sources, and concerning the validity of these doubts opinions may well differ. Those most familiar with the problem are the most sanguine of the probability of commercial success.

While it is undoubtedly true that governmental efforts can yet furnish assistance, there is a very serious doubt as to how far these efforts should be continued. The time seems to have arrived when the commercial interests should themselves squarely assume the tasks confronting them and the costs of what further experimenting is necessary. This they have been slow to do, but there is rapidly accumulating evidence that these interests are responding to the spur of necessity, and that sooner or later potash salts from American sources are to be upon the market. An early cessation of the European war might delay but can no longer stop the development of our potash resources.

The Value of Standards in the Manufacture of Automobiles. K. W. ZIMMERSCHIED. (*Midwest Section Society of Automobile Engineers,* October, 1915.)—The most potent factor in the brilliant rise of the mechanical industry of America is the almost universal adoption of the principles of interchangeable manufacture. There are underlying reasons for the opportunities that have arisen continually before us, but no nation with so few skilled mechanics as ours could have ever taken advantage of these opportunities so adequately without possessing the genius to conceive the idea of assembling things from parts wholly produced by automatic machinery. But even such genius could not have brought success had the final conception failed to include the provision that all such automatically-produced parts should be so alike as to be interchangeable. The whole scheme of interchangeable manufacture is based upon the use, conscious or not, of standards of measure, of form, of material quality, of workmanship.

In the automobile industry it was found that many of the older established standards were inadequate for the conditions encountered in the building and maintenance of high-duty road mechanisms and have been modified or amplified to meet these conditions. In addition to standards of form, the new varieties of steel as well as non-ferrous alloys have been standardized, and precise specifications eliminate the mystery surrounding various alloy steels sold at high prices under various trade names.

Establishing practical standards is one of the most valuable activities of the Society of Automobile Engineers. Those standards established by it have proved adequate to meet a great variety of conditions, and nearly all of them have been accepted widely by the trade.

American-Made Tracing Cloth. ANON. (*Engineering Magazine,* vol. 1, No. 2, November, 1915.)—To the National Tracing Cloth Company is due whatever credit there might have been in placing American-made tracing cloth upon the market. For years American consumers were dependent on imported cloth, good, bad, and indifferent. Since the inception of the National Tracing Cloth Company, about five years ago, it is possible to get a cloth of American make of superlative grade and at a price considerably lower than that of the best imported brands, to which it is in no degree inferior.

National tracing cloth is made at Saylesville, R. I., the manufacturing plant being part of the Sayles' Bleacheries. The company started rightly by using a basic cloth of exceptional excellence as a foundation of its finished article, made from selected yarn of long staple, giving it a stability of character both in material and finish, so desirable when a drafting department desires to file away its drawings for reference in after-years.

THE CRACKING AND DISTILLATION OF PETROLEUM UNDER PRESSURE.*

BY

BENJAMIN T. BROOKS, Ph.D.,

Mellon Institute of Industrial Research, University of Pittsburgh.

THE great increase in the consumption of gasoline during the last decade induced the apprehension that a serious shortage of petrol, or gasoline, suitable for use in motor vehicles would result. This has recently resulted in a small flood of patents describing various processes which have for their object the conversion of the heavier and generally less valuable petroleum oils into gasoline. The public press does not even yet seem to be aware of the steady development which has been going on in the petroleum industry and which now enables us to say with certainty that no serious shortage of gasoline will ever inconvenience the automobile trade so long as petroleum of even the heavier grade is produced in anything like the quantity now being brought forth in the world's various petroleum-producing centres. Several independent groups of investigators have contributed to the solution of this problem, and, although this cannot be considered a closed chapter of industrial research, certainly more than the preface has been written, since more than one method has been shown to be capable of successful, commercial, large-scale operation.

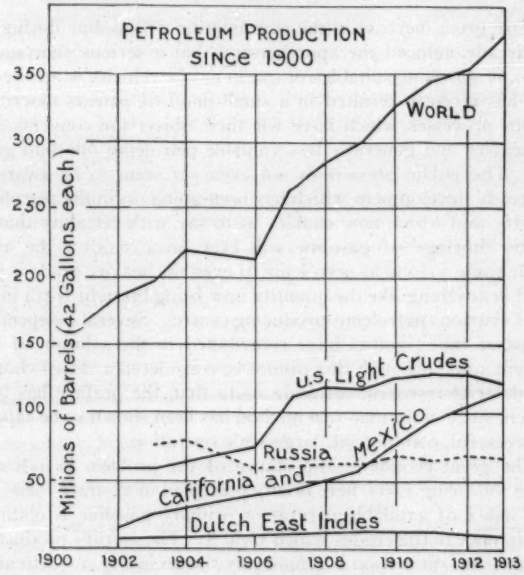
The great economic importance of the problem is indicated by the following facts, here briefly presented in abstract form. A good index of available natural or primary gasoline is obtained by reference to the crudes which yield it. The world's production of petroleum since 1900 is graphically shown in Fig. 1. Attention should be called to the fact that the greatest increases in the production of crude have been in fields yielding heavy oil containing little or no gasoline, as is the case with Californian and Mexican oils.

In 1910 there were in the United States, as nearly as can be ascertained from the registration statistics, about 350,000 motor

* Presented at the meeting of the Section of Physics and Chemistry held Thursday, October 7, 1915.

vehicles in use; in 1911 the figure given was 550,000; in 1912 this total had mounted to 990,700, and, by the end of 1914, 1,808,000 motor vehicles had been registered.[1] More accurate data are available, giving the number of automobiles manufactured in this country since 1903. This is shown graphically in Fig. 2.

FIG. 1.



World's production of petroleum since 1900.

The economic aspects of the motor fuel question are more fully discussed by the author in a recent number of the *Journal of Industrial and Engineering Chemistry*.[2] The following repre-

[1] *Oil Paint and Drug Reporter*, March 15, 1915. *The Automobile* for August, 1915, states that the registration statistics show that 2,070,900 cars are now in use in the United States.

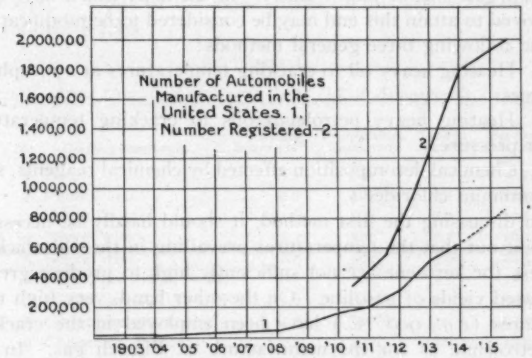
[2] *J. Ind. and Eng. Chem.*, 1915, 7, 177.

sent the principal factors in the question of an increased supply of motor fuel and show that cracking methods for the manufacture of gasoline must become of increasing importance:

1. The supply of motor fuel can be nearly doubled by employing spirit of about 56° Be. gravity and constituting the entire distillate boiling below 200° C. from high-grade crudes yielding gasoline.

2. Natural-gas gasoline, made by cold compression of "wet" natural gas, may yield, in the United States, 500,000 to 600,000 barrels. If this is blended with heavy naphtha so as to produce a heavier mixture suitable for use in automobiles, the total in-

FIG. 2.



Automobile statistics for the United States.

crease available will be approximately 1,000,000 barrels, or less than 4 per cent. of the production of "primary" gasoline distilled from crudes in the United States.

3. The shale oil industry is of no importance in this country, and in England is practically in a static condition, and increased amounts of motor fuel can hardly be looked for from this source.

4. If all the by-product coke ovens now operating, or nearing completion, in the United States were equipped with benzol recovery plants, the total production of benzol would be approximately 30,000,000 gallons (recovering 2 gallons of benzol per

ton of coal). By the end of the present year about 7600 by-product ovens will be in operation in this country.[3]

5. The price of 95 per cent. alcohol for industrial purposes is normally 30 to 35 cents per gallon. This alcohol has only about 60 per cent. of the calorific power of gasoline and has not been employed for motor fuel in England in normal times, when gasoline sold for 40 to 42 cents per gallon.

The earlier attempts to convert heavy petroleum hydrocarbons of high boiling-points into lighter, more volatile products were carried out with the object of increasing the yield of illuminating oil. But in very recent years the cracking problem has been attacked anew and with the object of increasing the yield of gasoline, or motor fuel. The methods which have been employed to attain this end may be considered to be modifications of the following three general methods:

1. Heating heavy oil to cracking temperatures at atmospheric pressure.

2. Heating heavy petroleum oils to cracking temperatures under pressure.

3. Chemical decomposition effected by chemical reagents, such as aluminum chloride.

In discussing the first method, it should hardly be necessary to point out that the temperatures prevailing in the old cracking process for kerosene are not sufficiently high to produce greatly increased yields of gasoline. On the other hand, very high temperatures (*e.g.*, 900° C.) have been employed in the cracking of petroleum, as for the manufacture of Pintsch gas. In the latter process, about one gallon of light volatile liquid is obtained by compressing 1000 cubic feet of the gas.[4] A sample of this product, Sp. gr. 0.830, recently examined in this laboratory, yielded 88 per cent. distilling below 115° C. It was a very highly unsaturated product, and when carefully treated with cold con-

[3] Püning (*Iron Trade Review*, 1913, 625, 653) gives 6200 by-product ovens in the United States at the end of the year 1913.

If the number of by-product ovens becomes sufficient to supply the 40,000,000 tons of coke now consumed by our blast furnaces when they are working full capacity, we can reckon on a possible annual production of benzol of about 80,000,000 gallons.

[4] Armstrong, *J. Soc. Chem. Ind.*, 1884, 464.

centrated sulphuric acid this sample lost 48.0 per cent. to the acid. The principal constituent of the remainder was benzol.

Experiments carried out in this laboratory show that at temperatures within the range 430° C. to 600° C., Solar oil, Sp. gr. 0.8862, yielded from 3 to 20 per cent. of the gasoline boiling below 150° C. The gasoline so produced was highly unsaturated, the loss on treating with one-fifth volume of concentrated sulphuric acid averaging about 28 per cent. The presence of contact substances appeared to be without effect, except in the case of nickel, when the amount of gas produced was greater and the gasoline fraction of the resulting product showed a much greater loss to the sulphuric acid than when other contact substances were employed. A few of the experiments of this series are noted in the following table:

TABLE I.

Results of the Crackinig of Texas Solar Oil at Atmospheric Pressure.

No.	Contact substance	Per cent. boiling below 150°	Temperature C. Centigrade	Time in hours	Per cent. loss gas and coke
1.	None	8.3	500°	0.5	8.7
2.	Pumice	8.8	420°	2.0	12.8
3.	Pumice	15.6	500°	2.0	17.5
4.	Nickel wire	12.3	500°	2.5	16.1
5.	Nickel wire	18.8	500°	5.0	16.5
6.	Nickel on Al_2O_3 + H	10.5	500°	2.5	15.1
7.	Nickel on Al_2O_3 + H	17.9	600°	2.0	30.8
8.	Copper on charcoal	14.7	500°	2.0	13.1
9.	Copper on charcoal	9.4	450°	6.0	12.0
10.	Copper gauze	14.1	500°	2.0	11.4
11.	Copper gauze	15.2	500°	2.5	11.8
12.	Copper gauze	18.8	500°	4.5	17.1
13.	Copper gauze + H_2O	15.5	600°	2.0	11.1
14.	Iron	4.5	400°	2.7	...
15.	Iron + H_2O	8.6	450°	2.0	...
16.	Iron + H_2O	8.5	480°	3.5	...

If the cracking of a paraffin hydrocarbon is expressed by the equation—$RCH_2 - CH_2CH_2R_1 \longrightarrow RCH_3 + CH_2 = CH.R_1$—one might expect that the per cent. by volume of unsaturated hydrocarbons would approximate 50 per cent. of the product. However, separation of carbon and gaseous products, polymerization

of the olefines, and formation of naphthenes occurs.[5] I have found formaldehyde and formic acid among the products of the autoxidation of cracked oils, which fact may be considered as an indication of the presence of the methene group ($=CH_2$).[6]

It is, of course, obvious that, if hydrogenation could be carried out successfully in a commercial way, the customary treatment with sulphuric acid could be dispensed with. However, we have found that the ordinary desulphurization methods, even when most carefully carried out, apparently left traces of sulphur in the oil, so that, after comparatively very little use, the catalysts, both nickel and palladium, were rendered inactive.

In view of the recently-proposed method of Bergius, of hydrogenating without a metallic catalyst, an experiment was made in which a sample of cracked gasoline, iodine number 55.0, was maintained at 196° C. for 30 hours under a hydrogen pressure of 3000 pounds per square inch. The iodine number of the gasoline, after the experiment, was 52.9, an effect probably accounted for by polymerization, since a similar reduction in iodine number was brought about in an atmosphere of nitrogen.

Since petroleum technologists have come to associate the characteristic, strong and unpleasant odor of cracked oils with olefines, and sometimes attribute the objectionable odor to their presence, it is worth while to note that highly-cracked gasoline, which had been treated with alkaline plumbite, or thoroughly desulphurized by copper oxide, had lost nearly all of its offensive, so-called odor of cracked oils. Metallic sodium is even more effective in producing sweet-smelling gasoline, although the percentage of olefines remains unchanged. Pure olefines have a sweetish, agreeable odor. The odor of pure olefines or of cracked gasolines, which have been purified as by metallic sodium, while agreeable, is not exactly like the customary odor of gasoline, and, it might be said, neither is exceedingly pure normal heptane. Much to my surprise, I found that the cracked oils, desulphurized and otherwise purified by metallic sodium, held their water-white color and were very decidedly better, even in respect to odor, than good commercial "primary" gasoline, after the two samples had

[5] Engler and Gruning, *Ber.*, **33**, 1900, 2915. Engler and Lehmann, *Ber.*, **30**, 1897, 2367. Krämer and Spilker, *Ber.*, **33**, 1900, 2268. Nastjukoff, *J. Russ. Phys. chem. Ges.*, 1904, 881.

[6] Cf. Wallach, *Ann.*, 343, 1905, 34.

been exposed side by side to light and air for six months. The same marked difference was noted in the case of a sample of "primary" gasoline from Oklahoma crude, part of which was treated with metallic sodium and the second part "refined" by sulphuric acid in the usual manner. Sulphur compounds, perhaps in the sulphite condition, appear to catalyze the autoxidation of such refined oils, although Willstätter [7] has shown that sulphur, in the form of the element at ordinary temperatures, does not accelerate oxidation. The offensive odor of cracked petroleum oils is due to small quantities of sulphur compounds, naphthenic acids, and basic nitrogen compounds, the latter probably of the pyridene type. Pure olefines slowly assume a pungent, disagreeable odor by autoxidation, peroxides, formaldehyde, formic acid and traces of other fatty acids, carbon dioxide, and resinous products being formed.

A number of processes have been patented which propose to hydrogenate the unsaturated hydrocarbons as they are formed, as by placing platinum or palladium in the cracking still. Others pass the oil vapors with steam through heated pipes, the claim being made that the steam and oil, or steam and carbon, react to give carbon monoxide and hydrogen, a claim which can undoubtedly be substantiated, if sufficiently high temperatures are employed. Another method, which is said to have been tried on a large scale, is that of passing the steam and oil vapors together over scrap iron at 540° to 650° C. Other processes propose cracking in the presence of nickel with or without steam. Another patentee employs oil and steam vapors over "red-hot" alumina, and another introduces coke into the oil-steam combination, an addition which those familiar with the cracking problem doubtless deem an unnecessary expedient. Our results with the steam-iron method indicate that hydrogenation of olefines under these conditions is not appreciable, and W. A. Hall [8] has recently recorded experiences with the oil-steam-iron process which confirm our own. Hall states that he found steam totally inadequate as a means for preventing carbon deposits, and that "the extent of the hydrogenation was hard to determine, but, at all events, the spirit produced was so largely unsaturated that hydrogenation

[7] *Ber.*, 1914, 2801.
[8] *Engineering*, 1915, 250; *J. Gas Lighting*, 1915, 455.

could not have been of much consequence, and, although we do not know what became of the small amount of hydrogen evolved, we do know that the oxygen was sufficient to destroy completely the tubes in a surprisingly short space of time."

Another group of patents describes heating heavy oil under pressure, subsequently distilling at atmospheric pressure. The early experiments of Thorpe and Young,[9] who heated paraffin under "a high pressure," obtaining a light oil which contained pentane, hexane, octane, and nonane, and the work of Ipatiew [10] on the polymerization of ethylene, probably the most stable olefine hydrocarbon, and the work of Engler,[11] who showed that typical petroleum olefines could be converted into saturated naphthenes, induced us to follow up this line of work. Engler and Halmai [12] heated a heavy cylinder oil to 430° to 470° C. under 120 atmospheres pressure and by three successive treatments obtained 52 per cent. boiling below 180° C., specific gravity 0.755. This method has also been described recently by Snelling,[13] who employs 800 pounds pressure. In order to compare the results obtainable by heating under pressure and subsequently distilling at atmospheric pressure, we heated Oklahoma reduced oil, containing no constituents boiling below 275° C., for two hours under a pressure of 180 pounds per square inch, the pressure being that developed by its own vapors and decomposition products. We obtained 5 per cent. gasoline by subsequently distilling at atmospheric pressure. In another experiment in the same apparatus, with the same quantity of reduced oil and also of two hours' duration and 180 pounds pressure, we obtained 30 per cent. of gasoline by distilling the gasoline as fast as formed.

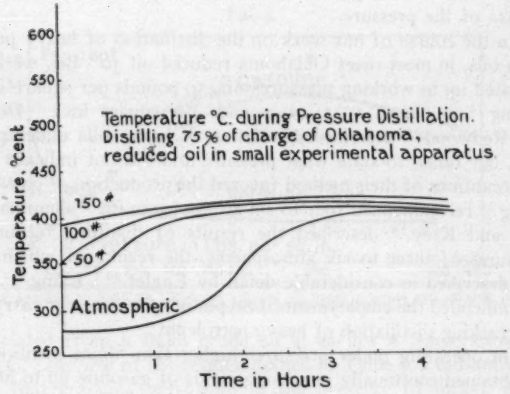
Little light, if any, can be thrown on this matter by attempting a mathematical discussion of the equilibria in such so-called systems. Suffice it to be said that according to familiar principles of equilibria, which we may qualitatively apply for the purpose of explanation, this difference, noted above, is evidently due to the fact that the gasoline hydrocarbons themselves are decomposed and, to obtain maximum yields, should be removed from the source

[9] *Chem. News*, 1871, **23**, 124; 1872, **26**, 35.
[10] *Ber. d. deut. chem. Ges.*, 1911, **44**, 2978.
[11] *Ibid.*, 1900, **33**, 2915; 1909, **42**, 4610, 4613, 4620; 1910, **43**, 388.
[12] *Ibid.*, 1910, **43**, 397.
[13] *Bull. Am. Inst. Mining Engineers*, 1915, 695.

of heat or sphere of reaction. Also, if the lighter, more volatile products are removed as fast as formed, the heavy residual matter in the still becomes continually hotter. This is shown by the following temperature curve obtained during distillation of Oklahoma reduced oil under 100 pounds pressure, the temperature being recorded by a thermo-couple in the oil several inches from the still bottom (see Fig. 3).

Operating by the Snelling method, the temperature within the still becomes lower and lower, if constant pressure is maintained, due to the accumulation of gases and volatile products in

FIG. 3.



the still. This must have the result that the more stable hydrocarbons are not cracked. The emphasis Snelling places on the ratio of the volume of the charge to the total volume of the still obviously is to be interpreted that, if one were to fill the still nearly full, one could easily attain excessive and dangerous pressures, such as the 800 pounds mentioned by Snelling, before temperatures sufficiently high to crack the oil would be reached. If the still is charged with only a relatively very small quantity of oil, say one-twentieth volume, the whole of it might easily be converted into gas and coke without producing the said pressure.

A modified form of the process of heating oil under pressure and subsequently distilling at atmospheric pressure has been patented by Testelin and Renard,[14] who describe heating oil in pipes to temperatures not exceeding 450° C. and maintaining "sufficient pressure on the oil to keep it in the liquid state." Clark[15] varies this by pumping the oil through heated pipes and passing the hot oil into a receiving drum, where distillation of the lighter products can take place. One object of the Clark method appears to be to minimize the deposition of coke in the heated pipes by the rapid passage of the oil through them. The Clark patent seems to be practically the old method of Benton, except that Benton permitted the lighter products to distil by *release* of the pressure.

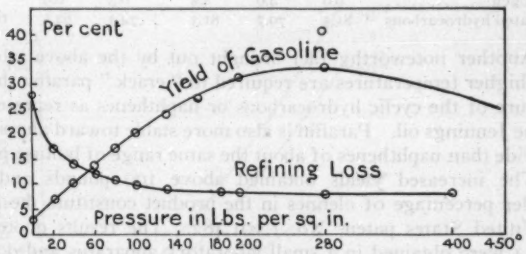
In the course of our work on the distillation of heavy petroleum oils, in most cases Oklahoma reduced oil 30° Be., we have operated up to working pressures of 450 pounds per square inch. Young[16] employed 10 to 20 pounds per square inch. Dewar and Redwood[17] described distillation of heavy oils under pressure, but failed to state what pressure and did not indicate that the conditions of their method favored the production of gasoline. Boleg[18] recommended four to six atmospheres for "illuminating oil," and Krey[19] described the results of distilling oil under pressures of three to six atmospheres, the results of which are also described in considerable detail by Engler.[20] Laing[21] also recommended the employment of 80 pounds pressure for carrying out cracking distillation of heavy petroleum.

On operating under pressures higher than those mentioned, we obtained continually increasing yields of gasoline up to about 250 pounds per square inch, when the yield diminished with further increase of pressure, the relative amount of coke and gas formed rapidly increasing beyond this point. The marked influence of pressure upon the percentage of olefines in the gasoline produced is also shown graphically in Fig. 4.

[14] English Patent 3413, February 10, 1913.
[15] U. S. Patent 1,119,496, December 1, 1914.
[16] English Patent 3345, December 27, 1865.
[17] U. S. Patent 419,931, 1890; 426, 173, 1891.
[18] *Chem. Rev.*, 9, 1898, 24.
[19] German Patent 37,728, 1886.
[20] *Ber. d. deut. chem. Ges.* 30, 1897, 2919.
[21] English Patent 11,757, 1890; 260,858, 1911.

This *decrease in the percentage of olefines* in the resulting gasoline is undoubtedly due to their polymerization, not to hydrogenation, although Ipatiew observed that, in the distillation of petroleum under pressure, the evolved gases become continually poorer in hydrogen as the pressure is increased, in spite of the higher temperatures required to maintain the higher pressures. At a given temperature it is obvious that increase of pressure would tend to prevent dissociation with the formation of gaseous products. Engler [22] obtained no hydrogen from kerosene by heating to temperatures below *470° C.* Uebbelohde and Woronin [23] showed that, in the presence of nickel, hydrogen was

FIG. 4.



Yield of gasoline by distilling Oklahoma reduced oil under pressure and refining loss of gasoline so produced on treating with sulphuric acid.

dissociated from a Baku crude oil at as low a temperature as 180° C. In view of the results, quoted in Table I, I did not consider that cracking petroleum in the presence of nickel, even under pressure, was likely to give a satisfactory product. Sabatier and Mailhe [24] propose to make highly unsaturated gasoline by cracking in the presence of red-hot nickel and subsequently hydrogenate the resulting product. Hall [25] cracks oil in the form of *vapor* at 600° to 650° C. in the presence of nickel and under 50 to 75 pounds pressure, and obtains a highly unsaturated product, but very rich in benzol and its homologues. The effect noted by Ipatiew is evidently that of pressure on the character of the

[22] "Das Erdol," I, 574.
[23] *Petroleum*, 1911, 7, 9.
[24] U. S. Patent 1,124,333.
[25] English Patent 17,121, 1913.

dissociation of the hydrocarbons. We have analyzed the gases evolved during distillation of Oklahoma reduced oil at 110 pounds pressure and find that the percentage of hydrogen in the evolved gases is extremely small.

TABLE II.

Gases from Cracking Distillations Under 100 Pounds Pressure.

	(a) From Jennings crude.			(b) Paraffin.		
Sample No.	I	II	III	I	II	III
Temperature in still	340°C.	415°C.	422°C.	417°C.	432°C.	437°C.
CO_2	1.2	0.5	0.0	0.0	0.0	0.0
CO	1.2	0.5	1.3	0.0	0.0	0.0
Illuminants	15.4	15.3	13.0	25.4	37.0	33.5
Hydrogen	0.0	4.0	4.4	0.3	0.9	3.0
Saturated hydrocarbons	81.5	79.7	81.3	74.3	62.1	63.5

Another noteworthy fact brought out by the above table is that higher temperatures are required to "crack" paraffin than a mixture of the cyclic hydrocarbons or naphthenes as represented by the Jennings oil. Paraffin is also more stable toward aluminum chloride than naphthenes of about the same range of boiling-point.

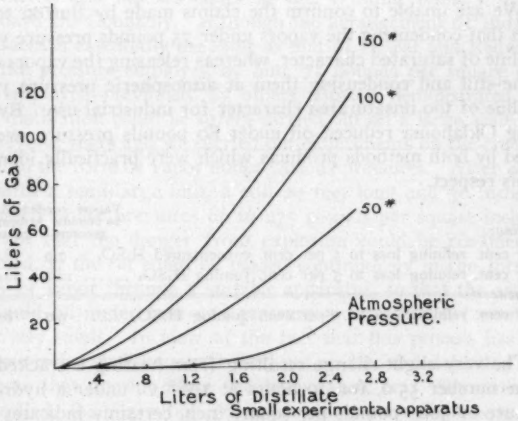
The increased yields obtained above 100 pounds and the smaller percentage of olefines in the product constitute the basis of United States patent No. 1,101,482. The results quoted in Fig. 4 were obtained in a small laboratory apparatus and do not represent the maximum yields obtainable, nor the highest quality of product. The ratio of heating surface to the volume of oil in the still affects markedly the rate at which cracking distillation can be carried out. Were the process merely one of distillation, this would seem too obvious to mention. However, the *cracking* of the oil apparently occurs chiefly at the heated surfaces, where the heat is supplied to the oil, and considerable time must be allowed for the oil to be cracked to the lighter hydrocarbons and *too rapid distillation prevented,* as by slow firing and refluxing the heavier fractions back into the still. *Slow* and less intense firing of the still also has the result of greatly diminishing the percentage of olefines in the gasoline produced, although the yield of gasoline is much increased.

We have found that the amount of gas evolved and coke deposited increases very rapidly as the working pressure is increased beyond 100 pounds. This figure varies considerably in different apparatus and with different distillation rates. Small laboratory

apparatus gives more coke and gas and more highly unsaturated gasoline than large apparatus. The rate at which gas is given off during distillation of a given charge of oil at constant pressure is greatest during the coking stage, *i.e.*, after 85 per cent. of the charge has been distilled—a procedure naturally not carried out in practice. This is shown by the curves in Fig. 5.

The *percentage of coke deposited* also varies greatly according to the form of the apparatus and the method of operating. Thus very little coke is deposited in an ordinary horizontal still during

FIG. 5.



Gas evolved on distilling three litres Oklahoma reduced oil in small experimental apparatus.

distillation at 100 pounds, if not more than 60 per cent. of the charge is distilled. This will naturally vary greatly with the character of the oil charged into the still. With clean paraffin distillate in a still of the Burton type, the amount of coke deposited in 24 hours from 200 barrels charge rarely exceeds 125 pounds. We have found that, if the heating surfaces are vertical, the quantity of coke deposited is not more than one-fifth as much as is obtained under the same conditions but with the heating surfaces horizontal, as on an ordinary still bottom. If the distillation is not carried out beyond 60 per cent. of the charge, a large part

of the coke remains suspended in the residual oil as gritty, sandlike particles.

We have made use of the above-mentioned facts by so operating [26] that the heating surfaces are vertical, maintaining a large ratio between heating surface and volume of oil charged and removing the sandlike coke particles, by gravity and flow of oil through the apparatus, into a cooler zone, which prevents their cementing together in the form of a hard, compact mass. Another patentee [27] places false bottoms in horizontal cylindrical stills, which collect much of the coke that would otherwise deposit on the hot bottom.

We are unable to confirm the claims made by Burton to the effect that condensing the vapors under 75 pounds pressure yields gasoline of saturated character, whereas releasing the vapors close to the still and condensing them at atmospheric pressure yields gasoline of too unsaturated character for industrial use. By distilling Oklahoma reduced oil under 80 pounds pressure, we obtained by both methods products which were practically identical in this respect.

	Vapors condensed under 80 pounds pressure	Atmospheric pressure
Gasoline:		
Per cent. refining loss to 5 per cent. concentrated H_2SO_4 ..	7.9	8.0
Per cent. refining loss to 5 per cent. fuming H_2SO_4	12.2	12.0
Kerosene:		
Per cent. refining loss to 5 per cent. fuming H_2SO_4	9.0	8.0

The very slight change resulting from heating a cracked oil, iodine number 55.0, for 30 hours at 196° C. under a hydrogen pressure of 3000 pounds per square inch, certainly indicates that polymerization of petroleum olefines does not occur to an appreciable extent below 200° C. The experiments of Semmler [28] on the polymerization of isoprene, myrcene, and other hydrocarbons by heating under pressure are interesting in this connection. The polymerization of butadiene derivatives by heat and pressure occurs much more readily than is the case with other olefines, at least so far as known. By heating myrcene four hours at 250° to 260° C., Semmler obtained a 50 per cent. yield of the diterpene

[26] U. S. Patent 1,131,309.
[27] Humphrey, U. S. Patent 1,122,000; 1,122,003. 1914
[28] *Ber. d. deut. chem. Ges.*, 1913, 1569.

$C_{20}H_{32}(F_3)$. It should be noted that the product is still highly unsaturated, containing three double bonds. It is my opinion that during the distillation of petroleum oils under pressure polymerization of the olefines formed occurs in the still proper, where higher temperatures, 380° to 420° C., prevail, not, as claimed by Burton, in the water-cooled, condenser coils, where much lower temperatures are the rule. We are now engaged in studying this question of polymerization of olefines by heat and pressure at regular temperature intervals above 200° C.

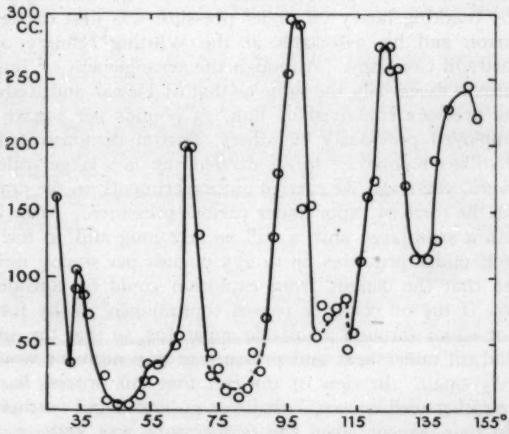
However, the successful manufacture of gasoline on a large scale by cracking heavy oil under pressure was first carried out by Burton and his associates at the Whiting refinery of the Standard Oil Company. Although the arrangement of Burton's apparatus is essentially the same as that of Dewar and Redwood, and the pressure employed by him, 75 pounds per square inch, was employed previously by others, Burton demonstrated that such distillation could be *safely* carried out on a large scale.

Several years ago we carried out experiments on the cracking of oil in the form of vapor under various pressures. After working with a semi-large unit, a still 20 feet long and 30 inches in diameter, under pressures up to 275 pounds per square inch, we believed that the danger from explosion could be considerably lessened, if the oil could be passed continuously in the form of spray or vapor through a suitable apparatus, so that the amount of liquid oil under heat and pressure at any moment would be relatively small. In view of the fact that this process has now become rather well known, I shall not go into detail further than to state that, except when the temperature was very carefully controlled, the deposition of coke was greater than when the apparatus contained liquid oil under the same pressure. Regulation of the pressure by permitting the gaseous products to accumulate or by introducing gas, such as hydrogen or water gas, is also a factor. Heavy oil cannot be completely vaporized at any except very low pressures. With the heavier oils, cracking begins at once when vaporization is attempted. Tar or coke particles coming into contact with the heated walls of the apparatus become cemented there, whereas when filled with oil the rather violent motion of the oil in ebullition tends to entangle and carry away the coke particles, and the heavy residue, carrying as much as 15 per cent. of sandlike coke, depending upon the conditions of

operation, is slowly swept out of the apparatus when operating on the continuous system as we have done, or is caught on the false bottoms provided for the purpose in the Burton-Humphries method.

We have examined the gasoline made from Oklahoma reduced oil, 30° Be., by distilling under 100 pounds pressure and find that, in addition to approximately 8 per cent. of benzol, toluol, and metaxylol, the gasoline appears to consist chiefly of normal paraffin hydrocarbons.[29]

FIG. 6.



Fractional distillation curve for gasoline made by distilling Oklahoma reduced oil under 100 pounds pressure.

The public press has recently given a great deal of space to the possibility of manufacturing benzol and toluol by cracking petroleum vapors, at temperatures within the range 600° to 650° C. and under 75 pounds pressure. A communication to the author from W. A. Hall states that a large plant, erected at Thames Haven, England, has been taken over by the government for the manufacture of benzol and toluol, employing as a raw material the ordinary fuel oil used in the British Navy. Mr. Hall says: "I can state that the spirit derived from this cracking operation

[29] Experimental work done by I. W. Humphrey.

contained 22 per cent. of C. P. toluol, as determined by Sir Boverton Redwood, who has had the whole matter in charge."

The formation of aromatic hydrocarbons from petroleum oils has heretofore been assumed to be due to complex and little-understood changes, such as dehydrogenation of naphthenes and the formation of acetylene, and the condensation of the latter to benzene and its homologues.

We have found the above-named aromatic hydrocarbons in gasoline made by cracking heavy Oklahoma reduced oil under a pressure of 100 pounds per square inch. Treatment of the gasoline so obtained by liquid sulphur dioxide gave 10.0 per cent. of olefines and aromatic hydrocarbons, which mixture was fractionated several times, and the fractions whose boiling-points corresponded to the boiling-points of benzol, toluol, and xylol were nitrated in the usual manner, water added, and the crude crystalline mass thus obtained recrystallized several times from alcohol. We obtained in this way 1-, 3-dinitrobenzol, melting-point 90° C.; also 2-, 4-dinitrotoluol of melting-point 70° C., and 2-, 4-, 6-trinitrometaxylol, melting at 182° C.

Since relatively little gas is evolved when distilling under 100 pounds pressure, and since the gas evolved contains not more than 4.4 per cent. hydrogen, it appears highly improbable that the aromatic hydrocarbons in question are produced, either directly or indirectly, by a process of splitting off of hydrogen. Since benzol and a few of its simpler homologues have been found in all petroleums which have been thoroughly examined, I believe that the occurrence of benzol, toluol, and xylol in the gasoline made by cracking heavy oils under the conditions described above is to be explained by the splitting or "cracking" of high-boiling complex hydrocarbons,[30] containing the phenyl radicle, for example, such as $C_6H_5.C_{10}H_{19}$, which would be the empirical formula for a phenyl derivative of the naphthene $C_{10}H_{20}$.

[30] Jones and Wheeler (*J. Chem. Soc.*, 1914, 2562) have shown that hydrocarbons of the aromatic series are produced in the distillation of coal at 350° C., or below the temperatures at which hydrogen is split off. They suggest that aromatic compounds may be formed by reactions such as the following:

Naphthalene

Further evidence in support of this hypothesis is found in the fact that gasoline made by cracking Oklahoma reduced oil by anhydrous aluminum chloride contains a relatively large percentage of benzol, toluol, and xylol. It is known that the higher benzol homologues are broken down by aluminum chloride. A hydrocarbon of the type $C_6H_5C_{10}H_{21}$ would therefore be expected to yield a mixture of decomposition products containing a small percentage of benzol. One litre of the gasoline made by cracking with $AlCl_3$ was extracted four times with liquid sulphur dioxide, one pound being employed for each successive extraction. The gasoline was cooled to $-15°$ C. and thoroughly shaken with the liquid sulphur dioxide in a large Dewar flask. From one litre of this gasoline we obtained 325 c.c. soluble in liquid sulphur dioxide, which yielded the following:

Fraction	Volume	Result of nitration
45°– 90° C.	75 c.c.	3.6 g. dinitrobenzol
90°–120° C.	85 c.c.	13.8 g. dinitrotoluol
120°–145° C.	55 c.c.	39.6 g. trinitroxylol

This hypothesis is further supported by our finding that pure paraffin, on cracking by distillation under 100 pounds pressure, yields gasoline free from benzol hydrocarbons, and, on the other hand, synthetic phenyl-paraffins are broken down by cracking, as in pressure distillation or by heating with aluminum chloride, giving benzol and its simpler homologues among the reaction products.

The phenyl paraffin was prepared by chlorinating ordinary white commercial paraffin until the gain in weight was equivalent to that required by the formation of the monochloride, the paraffin being considered as a mixture of hydrocarbons of the mean molecular weight corresponding to $C_{24}H_{50}$. This chlorinated product was dissolved in about four times the quantity of benzol required by the reaction and treated with 7 per cent. anhydrous aluminum chloride at room temperature. After standing six hours the mixture was warmed to 80° C., until HCl was no longer evolved. The excess benzol was completely removed by distillation with steam, and the product separated from water and dried. To 500 grammes of this product 35 grammes anhydrous of aluminum chloride were added and the mixture strongly heated for four hours, the reaction product being partly refluxed back into the

distilling flask. On rectifying the distillate, 55 c.c. of benzol, boiling-point 78° to 85° C., and 11 c.c. of toluol, boiling-point 105° to 115° C., were obtained, which products were further identified by conversion into the dinitro-derivatives.

Two and one-half kilos of the synthetic phenyl paraffin, from which free benzol had been carefully removed, were subjected to distillation at 75 pounds pressure during a period of three hours. The distillate, 1500 c.c., was fractionated, and the fractions, 70° to 100° C., 100° to 115° C., and 115° to 145° C., examined for aromatic hydrocarbons by nitration.

Fraction	Volume in c.c.	Grammes dinitro-derivative
70°–100° C.	112	25 dinitrobenzol
100°–115° C.	150	40 dinitrotoluol [21]
115°–145° C.	272	

There are, of course, other conditions in which aromatic hydrocarbons are formed by complex reactions which take place at much higher temperatures. Such conditions obtain in the Hall process carried out at about 650° C., and in the manufacture of Pintsch gas at about 900° C. Abundant evolution of gas and separation of carbon occur under these conditions.

When heavy petroleum oils are heated with anhydrous aluminum chloride, cracking occurs with the formation of gaseous hydrocarbons and gasoline and kerosene, and, if the higher boiling oils are refluxed back into the still, yields of 15 to 25 per cent. gasoline may be obtained, depending upon the conditions. This process has been recently patented. The gasoline made by this process is practically free from unsaturated hydrocarbons. Most of the sulphur present in the original oil is evolved as hydrogen sulphide, which may be removed from the distillate by washing with alkali. The gasoline so made is very sweet in odor and very stable to light and air. I have found that the characteristic odor of most commercial gasoline is in part due to traces of naphthenic acids, which may be isolated as the sodium soap by treatment with metallic sodium. The aluminum chloride gasoline is free from this odor; in fact, we have found that ordinary gasoline to which 2 per cent. of Russian naphthenic acids were added was

[21] This dinitrotoluol was recrystallized, obtaining the pure product, melting-point 70.0° C., thus proving its identity beyond any question. In preparing the original phenyl paraffin C. P. benzol was employed.

completely deodorized by slowly distilling with aluminum chloride.

In the cracking of hydrocarbons with aluminum chloride the nature of the reaction is obscure. The formation of definite compounds of hydrocarbons with aluminum chloride has been shown repeatedly. In view of this fact, and also that free hydrogen chloride (or hydrogen bromide when aluminum bromide is employed) is claimed to facilitate the cracking of certain hydrocarbons, the following series of reactions have been proposed to account for the phenomena:

$$\begin{bmatrix} C_6H_{11}.CH_3 \\ Al_2Cl_6 \end{bmatrix} \rightleftarrows \begin{bmatrix} C_6H_{11} \\ Al_2Cl_6 \end{bmatrix} + CH_3Cl.$$

$$\searrow \begin{bmatrix} C_6H_{11}CH_2 \\ Al_2Cl_6 \end{bmatrix} + HCl.$$

$$\begin{bmatrix} C_6H_{11} \\ Al_2Cl_6 \end{bmatrix} + HCl \rightleftarrows C_6H_{12} + Al_2Cl_6$$

It has been shown that in the practice of the method for the manufacture of gasoline the coke, which is formed in relatively large amount, may be kept scraped free from the still bottom by a mechanical stirring device.

By way of *résumé*, it should again be pointed out that, while a very large number of patents have been granted describing processes for the manufacture of gasoline from heavy petroleum oils, it should be borne in mind that it is almost impossible to decompose heavy petroleum oils without the production of more or less low-boiling hydrocarbons, no matter what method is employed, provided a suitable temperature, say 380° C. to 450° C., prevails somewhere in the series of operations. The chief difficulty in large-scale operation is the deposition of coke. In view of the public and private history of many so-called discoveries in this field, the heralding of any one process as being the best would at this time be premature. Undoubtedly several years must yet elapse before anything like a standard practice will have been evolved, and that company having had the most experience with large-scale operation will, by the various improvements introduced as a result of persistent, patient trial and experience, undoubtedly dominate the field for longer than seventeen years.

THE TRANSFORMATION OF COLOR-MIXTURE EQUATIONS FROM ONE SYSTEM TO ANOTHER.*

BY

HERBERT E. IVES, Ph.D.,

Physical Laboratory, The United Gas Improvement Company.
Member of the Institute.

THE reduction of color specification and measurement to the fewest possible terms has been done, to a limited extent, by the use of two systems of color analysis, each involving three factors. The first method is the trichromatic, in which the color in question is matched by a mixture of three primaries, a red, a green, and a blue. The other is the monochromatic, in which the color is matched by a mixture of a spectrum hue and white, and is defined in terms of its hue, saturation, and luminosity.

While each of these systems is theoretically simple, both become undesirably beset with complications and difficulties when put into practice. Putting aside for the present those difficulties caused by the differences in color vision existing between different individuals, attention may be directed here to three of the problems met with in using these two systems of color measurement. In regard to the trichromatic system, it is to be noted that a very large number of sets of primaries may be chosen, each set resulting in a different set of mixture proportions. In regard to the monochromatic system, it is to be noted that the measurement of one of the elements (namely, luminosity) presents great practical difficulty. The third point, concerning each method equally, is that measurements made by one system have practically never been so transformed as to be directly comparable with similar measurements on the other.

The second of these points—the difficulty of measuring the luminosity factor—is merely noted here. Assuming that it can be met by some acceptable means, the remaining two points present the problem to be handled in the present paper. How can measurements on one trichromatic system be transformed to another system? How can measurements on any trichromatic

* Communicated by the Author.

system be transferred to the monochromatic system and *vice versa?*

The material for such transformations is to be found in the writings of Abney [1] and of Koenig,[2] dealing with the methods of obtaining the fundamental color sensations. The fact that such transformations are possible and, what is more, necessary, has been frequently overlooked in color measurements that have been published, notably of illuminants. For this reason, and because some interesting light is thrown on the whole question of color measurement by attempting the coördination of the various systems, a brief presentation of the problem is thought warranted, even though little essentially new is developed.

THE COLOR-MIXTURE PYRAMID.

The approach to the problem will here be made through what seems to the writer the clearest method of representing the facts of color mixture; namely, by a space diagram—the color pyramid. A large number of pyramids can be constructed, depending upon whether the coördinates are rectangular or otherwise, and also upon the values of the units taken along different axes. A complete and general treatment of the problem would include all of the possible pyramids, and the relations between them—a complicated problem in solid analytic geometry. For the sake of simplicity a few special cases only will be taken; these, however, are sufficient to meet the practical problems of color measurement.

Imagine a three-color mixture instrument, whose primaries are three spectral wave-lengths, red, green, and blue. Let the primaries be taken in such relative proportions that their mixture makes white. Let these quantities of red, green, and blue be each given the scale value unity. Let the quantity of red in any mixture be represented by a length taken along the X axis of a system of rectangular coördinates, the amount of green by a length taken along the Y axis, and the amount of blue similarly along the Z axis.

Under these conditions we have a number of important relations:

1. Every mixture of red, green, and blue (*i.e.*, every color) is represented by a point in space.

2. The series of grays from black to white is represented by

the straight line whose equation is $R=G=B$. All series of colors of the same hue, but varying luminosity, are represented by straight lines drawn from the origin of coördinates (black).

3. All colors resulting from the positive addition of the three primaries lie inside a cube, one of whose corners represents black, the opposite corner white, the others the red, green, blue, yellow, purple, and blue-green obtained by taking the three primaries in unit quantity singly and in pairs.

4. The color resulting from the mixture of any two is obtained by completing the parallelogram of which two sides are furnished by the lines joining the origin and the points representing the colors. The hues of all mixtures of two hues are given by the straight lines lying in the plane bounded by the two lines representing the original hues.

5. Sections of the color pyramid taken normal to the black-white line are equilateral triangles and give all colors composed of the same quantity of the primaries. The size of a triangle is proportional to the quantity of red, green, and blue in any color represented by a point in the triangle. The relative amounts of red, green, and blue are given by the vertical distances of the point representing the color from the sides opposite the vertices representing each primary (these vertical distances being proportional to the three vectors from the origin to the point in the triangle plane). In these color triangles the hues of mixtures of two colors are on the straight line joining the two color points (this line being the intersection of the hue plane given above with the plane of the triangle). *Complementary colors* are colors whose connecting line passes through white, and which, therefore, may be mixed to produce white.

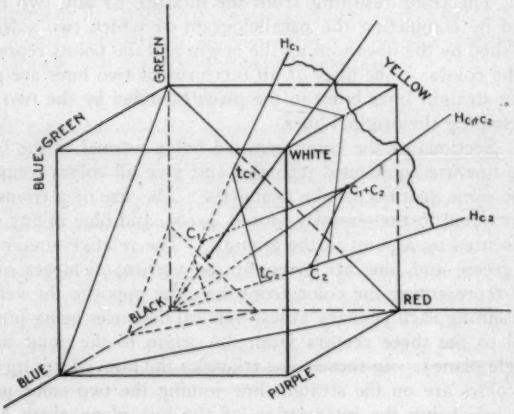
These relations are shown pictorially in Fig. 1.

It should not be necessary to point out that these relations apply only to color mixtures and not at all to mere plots of the relative energy values at three wave-lengths, or through three-color screens, as has been erroneously assumed in several instances.[6]

A restriction, applying chiefly to relation 2 but affecting all the discussion, may be mentioned here and kept in mind in all that follows. This is that we are to deal only with a range of intensities in which the Purkinje effect is not noticeable. The effect of this phenomenon is to twist the hue lines as they approach the

origin of coördinates. A section (color triangle) near the origin, corresponding to low luminosity, will show a set of hues such as the spectrum shifted from their normal positions. We shall in this discussion avoid the complications entering at low illuminations in the same manner that they must be escaped in practical measurement; that is, by considering all the measurements made at one fixed brightness or near it.

FIG. 1.



Spacial Representation of Three-color Mixture Phenomena.

Axes = primaries.
Vertices of cube = mixtures of primaries taken singly, in pairs, and all together.
C_1 and C_2, arbitrary colors.
C_1+C_2, color resulting from mixture of C_1 and C_2.
H_{C_1}, H_{C_2}, $H_{C_1+C_2}$, hue lines of colors C_1, C_2, and C_1+C_2.
t_{C_1}, t_{C_2}, hues of colors C_1 and C_2 in color triangle.
t_{C_1}, t_{C_2} = trace of hue line plane on color triangle.

TRANSFORMATION FROM ONE SET OF PRIMARIES TO ANOTHER.

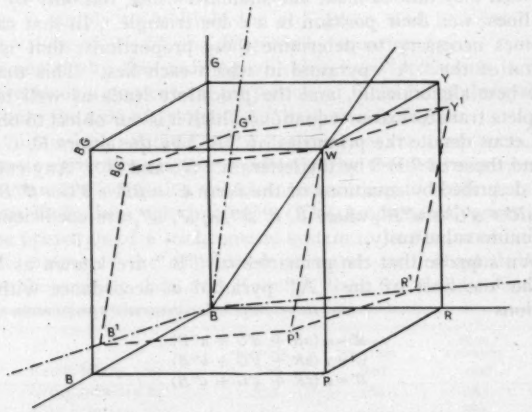
Let us assume two-color mixture instruments "A" and "B," using as primaries two different sets of red, green, and blue. Let the problem be to transform measurements made by instrument "B" into the values which would be obtained by instrument "A." Or, put differently, let us find how instrument "A" must be set to exhibit the color known only by its value as measured by "B."

For the solution of this problem it is necessary to know the values of the primaries of "B" on the scale of instrument "A." These may be obtained either by direct measurement, or by cal-

culation from the color-mixture curves of the spectrum, using spectrophotometric data. The graphic methods of obtaining the mixture values of any color of known spectral composition will be dealt with presently, so that we need note now only that the "A" values of the "B" primaries can be obtained, and proceed from that point.

As measured, these "B" primaries may already be in the proportions that mix to make the standard white to which both instruments are referred. If so, each primary may be placed at

FIG. 2.



Transformation from One Set of Primaries to Another.

R, *G*, and *B* = primaries of System A.
R', *G'*, and *B'* = primaries of System *B*, plotted in rectangular representation of System A.
Vertices of cube = mixtures of primaries of System A, singly, in pairs, and all together.
Vertices of parallelopiped = mixtures of primaries of System B, in their position in System A.

once in its position in the rectangular "A" pyramid. By the construction of the primary hue lines, and the parallels representing the additions of the primaries, a figure is obtained similar to the cube described under relation 3, containing all the colors obtainable by the positive addition of the "B" primaries. The new figure is not, however, a cube. The relation of these two figures, the cube and its equivalent, is shown in Fig. 2.

If we assume ourselves provided with an actual model of these two figures, having the same black and white apices, the process

of transforming "B" measurements into "A" units is simple. It is only necessary to note that with instrument "B" the primary hue edges of the enclosing figure have been, as is customary, assigned the value unity. If then we take any "B" measurement and multiply the red, green, and blue values by those values which the corresponding primary hue edges have in the figure "A," the resultant values are in shape for plotting in the "A" pyramid by the ordinary process of addition of vectors.

It is probably the more common case that the "B" primaries are not determined in the exact proportions (on the "A" scale) in which they mix to make the standard white, but only by their hue lines; *i.e.*, their position in a color triangle. In that case it becomes necessary to determine these proportions; that is, the section of the "A" pyramid in which each lies. This may be done best algebraically, and the procedure leads as well to the complete transformation equations which it is our object to obtain.

Let us denote the primaries of "A" by the letters R, G, and B, and those of "B" by the letters R', G', and B'. Any color is then described by equations of the form $C = \beta R + \beta' G + \beta'' B$ and $C = \alpha R' + \alpha' G' + \alpha'' B'$, where β, β' β'', α, α', α'', are coefficients of maximum value unity.

We suppose that the primaries of "B" are known as lying on the hue lines of the "A" pyramid in accordance with the relations

$$\begin{aligned} R' &= x\,(aR + a'G + a''B) \\ G' &= y\,(bR + b'G + b''B) \\ B' &= z\,(cR + c'G + c''B) \end{aligned} \tag{1}$$

where a, a', a'', b, b', b'', c, c', c'' are color triangle coördinates of the "B" primaries.

Since the standard whites of the two instruments are the same, we have

$$R' + G' + B' = R + G + B \tag{2}$$

Adding the three equations (1), substituting (2) for the summation of the left-hand side, and equating coefficients of like colors, we have

$$\begin{aligned} xa + yb + cz &= 1 \\ xa' + yb' + zc' &= 1 \\ xa'' + yb'' + zc'' &= 1 \end{aligned} \tag{3}$$

Solving these equations for x, y, and z, we obtain

$$x = \frac{-(bc'-b'c)(c''-c)+(c'-c)(bc''-b''c)}{(ac'-a'c)(bc''-b''c)-(bc'-b'c)(ac''-a''c)} \quad (4)$$

and similar terms for y and z. Substituting these in (1), we finally obtain the equations:

$$\begin{aligned} R' &= mR + nG + pB \\ G' &= m'R + n'G + p'B \\ B' &= m''R + n''G + p''B \end{aligned} \quad (5)$$

where $m = xa$, $n = xa'$, etc.

In order to transform any color-mixture equation obtained with instrument "B" into its value on instrument "A," the process is simply to multiply the red, green, and blue readings by the values of R', G', and B' given by equation (5).

Geometrically the meaning of these transformations is that we have made a non-cubical projection of the cube of the system "B" onto the axis of system "A," as shown in Fig. 2.

A numerical example of a transformation from one trichromatic system to another is afforded by the determination of the fundamental sensation values corresponding to readings taken with an F. E. Ives colorimeter.[3] (The fundamental sensations are the primaries of a trichromatic system to be discussed later.)

The values of the colorimeter primaries as derived through spectrophotometric data and Koenig's data for the distribution of the sensations through the spectrum are:

	Red sensation	Green sensation	Blue sensation
Red primary =	.780	.220	.000
Green primary =	.335	.580	.085
Blue primary =	.095	.019	.886

These coefficients, representing, as they stand, positions on a sensation color triangle, correspond to the coefficients a, a', b, c, etc., in (1).

Solving for x, y, and z, and then for m, n, p, etc., we obtain finally

	Red sensation	Green sensation	Blue sensation
Red primary =	.406	.115	.000
Green primary =	.500	.866	.127
Blue primary =	.094	.019	.873
	1.000	1.000	1.000

Suppose now a color is measured by the colorimeter as being

Red	.50
Green	.30
Blue	.10

By the use of the figures just obtained we find the sensation values to be

Red sensation	.362
Green sensation	.319
Blue sensation	.125

The different values of the mixture proportions of these two sets of primaries illustrate clearly the point emphasized in the introduction, that proper transformations are necessary before comparisons are permissible between measurements made by different three-color mixture instruments.

SPECIFICATION BY HUE, QUANTITY, AND QUANTITY OF WHITE.

We have just treated one of the practical systems of color measurement, the trichromatic, in its commonest form, where the three primaries are arbitrarily given equal values. It is our purpose to treat as well the other common method of color measurement, the monochromatic, in its most useful form, where the units are hue, luminosity, and luminosity of the white mixed with the hue. In going over from the trichromatic to the monochromatic it is desirable to treat two intermediate systems, theoretically on a par with these, but not in use. These are the system of specification by hue, quantity, and quantity of white, and the trichromatic system in which the primaries are assigned their luminosity values.

By "quantity" is here meant the sum of the coefficients of the three primaries. Thus the quantity of the color $aR + a'G + a''B$ is $a + a' + a''$.

"Hue" on the hue, quantity, and quantity of white system refers to some definite scale of hues, fixed by some convenient physical reference phenomena, the hues preferably completely surrounding the white centre axis of the pyramid. Such a scale is furnished, for instance, by the spectrum. Assuming such a scale of hues, it follows at once, from the properties of the color pyramid tabulated above, that any color can be formed by the mixture of white and some hue. This hue is the intersecting

line of the plane through the color, white, and the cone which forms the hue scale. In the color triangle this hue is found by the intersection of the line joining white and the color with the line representing the hue scale. For illustration, the spectrum hue of any color is obtained from the color triangle by drawing a line through the centre of the triangle and the point representing the color. This line continued cuts the curve representing the spectrum, from which the wave-length of intersection may be read off.

Our problem is to transform a trichromatic measurement to this new system. In order to do this our scale of hues must be definitely known in terms of the mixing proportions of the trichromatic primaries. In the case of the spectrum this means that we must know the mixture curves of the spectrum. For convenience in finding the hue of the color with which we are dealing, the hue scale mixture data should be plotted in a color triangle, as should also the value of the color. This is done quite simply by drawing parallels to the sides opposite each primary vertex, each parallel being distant from the side that fraction of the altitude of the triangle that its corresponding primary quantity is of the total quantity of all the primaries forming the measurement. The intersection of these parallels determines the position of a point of the hue of the color, as already indicated.

The hue having been thus determined, the rest of the problem is the determination of the white quantity.

Let the equation of the color be

$$C = aR + a'G + a''B$$

the total quantity of the color is

$$Q = a + a' + a''$$

The quantity of white given by the instrument with all these primaries utilized to full value is $1 + 1 + 1 = 3$.

To obtain the quantity of white to mix with the hue to match the color we have

$$q(R + G + B) + x(uR + vG + wB) = aR + a'G + a''B \qquad (6)$$

where quantity of white in color $= 3q = W = q \times$ quantity of instrument's maximum white, and the color triangle equation of the hue $= uR + vG + wB$.

Equating coefficients of like colors in (6), we obtain

$$q = \frac{ua' - va}{u - v} = \frac{va'' - wa'}{v - w} = \frac{wa - ua''}{w - u}$$

We thus have finally

$$\begin{aligned} Q &= a + a' + a'' \\ W &= 3\frac{ua' - va}{u - v} = 3\frac{va'' - wa'}{v - w} = 3\frac{wa - ua''}{w - u} \end{aligned} \tag{7}$$

with h, the hue, determined by some convenient scale number.

The converse problem, given the hue, the quantity, and the quantity of white, to find the coefficients of the three primaries, is solved from the same equations, giving

$$\begin{aligned} a &= \frac{Qu - \frac{W}{3}(2u - v - w)}{(w + v + w)} \\ a' &= \frac{Qv - \frac{W}{3}(2v - w - u)}{(w + v + w)} \\ a'' &= \frac{Qw - \frac{W}{3}(2w - u - v)}{(w + v + w)} \end{aligned} \tag{8}$$

The interest of this method lies entirely in the fact that the monochromatic system in practical use is one of its special cases. Its practical value is *nil*, for the reason that there is no direct method of measuring the "quantity" of a color. This factor is indeed entirely arbitrary, owing its existence to the practice of calling the amounts of the three primaries equal in white light.

LUMINOSITY RELATIONS IN THE TRICHROMATIC SYSTEM.

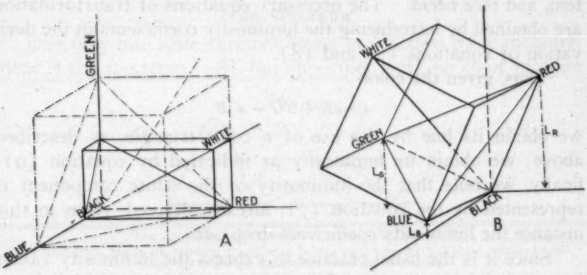
While there is no practical direct measure of the "quantity" of a color as above defined, there is a practical measure of a similar common quality of all colors. This is the luminosity, which may be measured directly, and which is the sum of the luminosities of such elements as are combined or mixed to produce the color.

It is possible to determine the luminosity values of a set of trichromatic primaries in the proportions with which they mix to make white, and build up a color pyramid with the luminosity values as the edges. The luminosity values are of quite different relative magnitude from the conventional equality which has heretofore been assigned to the three primaries. As a conse-

quence the mixture figure is no longer a cube, but (if rectangular coördinates are adhered to) a rectangular parallelopiped (Fig. 3 A). In place of the equilateral color triangle it is an irregular triangle, in which, however, white is still represented by the point of intersection of the bisectors of the sides.

This figure, which is the spacial representation of the measurements made with a three-color instrument, when the three primaries are recorded by their luminosity values, is difficult, if not impracticable, to work with. For that reason it will not be treated here. Instead the luminosity relations will be taken care of by ascribing to each primary, on the equal-value method of representation, a luminosity coefficient, with which it is to be multiplied if the luminosity value is desired. This is equivalent

FIG. 3 A. FIG. 3 B.



Methods of Representing Luminosity Relations in the Color Pyramid.

A. By assigning to the three primary lines lengths proportional to the luminosity of the primaries in their white-making quantities. The color cube becomes a rectangular parallelopiped.

B. By assigning to each primary a luminosity coefficient. By this method the convenient cube is retained, being merely tilted with reference to an auxiliary plane.

to referring all colors to a luminosity reference plane, the luminosity coefficients of the primaries being the sines of the angles made by the primary lines with this plane (Fig. 3 B).

Introducing the symbol L_G for the luminosity coefficient of a color, we have for the color

$$C = aR + a'G + a''B$$

the relation

$$LC = aL_R + a'L_G + a''L_B \qquad (9)$$

where L_R, L_G, and L_B are the luminosities of those quantities of the primaries which mix to make white. The luminosity of the

color relative to that of the white of the instrument (using its primaries in maximum quantity) is

$$\frac{L_C}{L_W} = \frac{aL_R + a'L_G + a''L_B}{L + L_G + L_B}$$

which may be written, using primed letters, as $L'_C = aL'_R + a'L'_G + a''L'_B$.

It is sometimes necessary to know the luminosity values of a new set of primaries. These are obtained by inserting the luminosity coefficient in equation (5) above.

SPECIFICATION BY HUE, LUMINOSITY AND LUMINOSITY OF WHITE.

We are now in a position to transform color equations from the trichromatic to the only practically used monochromatic system, and *vice versa*. The necessary equations of transformation are obtained by introducing the luminosity coefficients in the derivation of equations (7) and (8).

Thus, given the color

$$C = aR + a'G + a''B$$

we obtain its hue by the use of a color triangle, as described above; we obtain its luminosity as indicated by equation (9); finally, we note that the luminosity of the white component is represented by the equation (7), already derived, since in this instance the luminosity coefficients drop out.

Since it is the usual practice to express the luminosity values in terms of the luminosity of the reference white as unity, we can rewrite equation (7) in the form to be ordinarily used,

$$L'_W = \frac{ua' - va}{u - v} = \frac{va'' - wa'}{v - w} = \frac{wa - ua''}{w - u} \qquad (10)$$

where u, v, and w are the color-triangle coefficients of the hue, and L'_w is the luminosity of the white component in terms of the luminosity of the reference white.

In carrying out the converse process we determine the hue, luminosity, and the luminosity of white by observation. The mixture values of the hue are then found from the color-triangle plot of the hue scale (*e.g.*, the spectrum). Going through the process by which equation (8) was obtained, but carrying along luminosity coefficients, we obtain

$$a = \frac{uL'_C + L'_W[(w-u)L'_B-(u-v)L'_G]}{uL'_R + vL'_G + wL'_B}$$
$$a' = \frac{vL'_C + L'_W[(u-v)L'_R-(v-w)L'_B]}{uL_{R'} + vL'_G + wL'_B} \quad (11$$
$$a'' = \frac{wL'_C + L'_W[(v-w)L'_G-(w-v)L'_R]}{uL'_R + vL'_G + wL'_B}$$

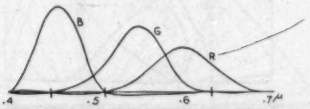
where u, v, and w, and the primed letters, have the significance above noted.

The data necessary for the transformation from a trichromatic system, of which there are as many as the possible choices of sets of primaries, to a monochromatic system using luminosity values, of which there are as many as there are hue scales, reduce to two sets. We must know the mixture values of the hue scale on the trichromatic system, and we must know the luminosity values of the trichromatic primaries.

THE SPECTRUM.

The only hue scale ever employed in practical color measurement is the spectrum. All the important work on color mixture

FIG. 4.



Diagrammatic Color-mixture Curve of the Spectrum.
The primaries, taken as spectral wave-lengths, are indicated by the short vertical lines. Note the negative values between the primaries.

has been done upon the spectrum. All colors being formed of mixtures of portions of the spectrum, it is necessary to know only the place of the spectrum in any color-mixture system in order to handle all practical problems of color measurement. The chief facts and relationships in regard to the spectrum are summarized below.

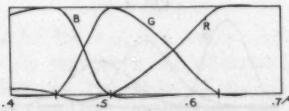
Three-color Mixture Curves on the Equal Primary Basis.—If the spectrum of white light is measured by a three-color mixture instrument a set of mixture curves of the spectrum is obtained. Of these the Maxwell curves are a good example. The areas of the three curves, red, green, and blue, are equal if the mixing quantities of the three primaries to make white are called equal. A diagrammatic set of such mixture curves is shown in Fig. 4. They show the values of a, a', and a'', using the symbols of the previous sections. A characteristic of these curves is that

for all real primaries, such as spectral colors, the mixture curves have regions of negative values. These negative values indicate that the mixture is less saturated than the spectral hue. The measurement is made in these regions by adding a small quantity of the negatively occurring primary or of white to the color being measured. This matter will be treated in the section dealing with the fundamental color sensations.

Three-color Percentage Curves on the Equal Primary Basis.—Instead of plotting the mixture curves as they are obtained, it is desirable for some purposes (*e.g.*, to assist in plotting the spectrum in a color triangle) to plot the percentage of each sensation at each wave-length. Such a percentage representation is shown in Fig. 5. Using the symbols of this paper, the figure shows values of $\frac{a}{a+a'+a''}$, $\frac{a'}{a+a'+a''}$, and $\frac{a''}{a+a'+a''}$.

The Spectrum in the Color Pyramid.—The white light spectrum is represented in the color pyramid by a curved line, start-

FIG. 5.



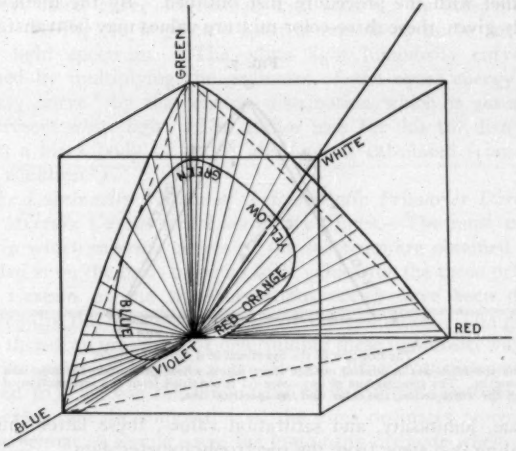
Percentage Mixture Curve of the Spectrum.
Relative proportions of the three primaries used at each wave-length, on basis of equal weighting of primaries as mixed to make white light.

ing at the origin of coördinates, rising to a high value on the red-green and green-blue sides, and returning to the origin near the red-blue side intersections. Mixtures of red and blue are practically missing in the spectrum. As a consequence the spectrum does not form a completely enclosing hue scale, such as was postulated in the discussion of specification by hue and other factors. This introduces the complication in the monochromatic method of specifying purples by the hue which must be mixed with the color to make white, instead of the hue which mixes with white to make the color. This, however, merely means a change of signs in the equation given above, and will be ignored here. The spectrum line is shown diagrammatically in the color pyramid in Fig. 6.

The Spectrum in the Color Triangle.—The spectrum is repre-

sented in the color triangle by the trace of the conical figure formed by the hue lines drawn through the spectrum line in the pyramid. The spectrum is plotted in the color triangle most simply from the percentage diagram shown in Fig. 5. If the altitude of the triangle is taken as the unit, every point in the percentage diagram has a corresponding point in the triangle. (The sum of the perpendicular distances of any point from the three sides of an equilateral triangle is equal to the altitude.) Fig. 7 shows a diagrammatic color-triangle spectrum plot. The

FIG. 6.



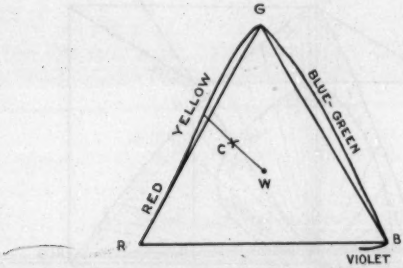
The Position of the Spectrum in the Color Pyramid.

relative quantity of red is given by the perpendicular distance of any point from the side opposite the red vertex, and similarly for the other primaries. The hues between red and blue are missing in the spectrum, as noted. The spectral hue of any color is obtained by drawing the line from white through the point representing the percentage composition of the color until it intersects the spectrum line.

The Determination of Mixture Values from Spectrophotometric Data.—One of the most useful services of a set of mixture

curves of the spectrum is to reduce spectrophotometric data to mixture values. In the case of transmissions of absorbing media it is merely necessary to multiply the mixture-curve ordinates by the transmission values at each wave-length.[8] The areas of the three reduced curves give at once the mixture values of the transmitted light. In the case of light not obtained by a process of absorption it is necessary to know the energy distribution of the light and compare it with the energy distribution which has been chosen for "white," and then to go through a multiplication process with the mixture-curve ordinates in a manner exactly parallel with the procedure just outlined. By the methods already given, these three-color mixture values may be transformed

FIG. 7.



The Position of the Spectrum in a Color Triangle.

The spectrum lies in general outside the triangle whose primaries (vertices) are spectral wave-lengths. The spectral hue of any color (*c*) is obtained from the intersection of the line through the white centre, the color, and the spectrum line.

to hue, luminosity, and saturation values, these latter thus demanding two steps from the spectrophotometer data.

Three-color Mixture Curves on a Luminosity Basis.—If, instead of calling the quantities of the three primaries which make white equal, we assign to them their luminosity values, a set of mixture curves results in which the three curves are of quite different areas. An important characteristic of this set of curves is that their summation gives the luminosity curve of the spectrum. The characteristics of mixture curves on a luminosity basis are shown in the sensation curves of Fig. 12. The ordinates, using the symbols of this paper, are aL_R, $a'L_G$, and $a''L_B$.

Three-color Mixture Percentage Curves on Luminosity Basis.

—In a similar fashion to the percentage mixture curves on the equal primary basis there may be plotted percentage curves on the luminosity basis.

The ordinates of such a plot are

$$\frac{aL_R}{aL_R + a'L_G + a''L_B}, \quad \frac{a'L_G}{aL_R + a'L_G + a''L_B}, \text{ and } \frac{a''L_B}{aL_R + a'L_G + a''L_B}.$$

The Luminosity Curve of the Spectrum.—Since the summation of the mixture curves of the spectrum on the luminosity basis is the luminosity curve of the spectrum, it is of importance to have this latter curve determined with accuracy by independent means. In Fig. 12 is given a spectral luminosity curve for the white light spectrum. (The white light luminosity curve is obtained by multiplying the ordinates of the equal energy luminosity curve [5] by that energy distribution which is assumed to represent white light. The author uses for this the distribution in a black body of 5000° absolute, as calculated from the Wien equation.[3])

The Luminosity Values of Trichromatic Primaries Derived from Mixture Curves and Luminosity Curve.—The most usual form in which mixture curves of the spectrum are obtained and recorded is on the basis of equal scale values for the three primaries. Certain of the transformations which have been dealt with require the luminosity values of the primaries. The problem is therefore presented of determining these luminosity values. For this purpose (unless a process of direct measurement is resorted to), we use the luminosity curve of the spectrum, remembering that the summation of the three ordinates representing the primaries should equal the luminosity ordinate when each primary is assigned its luminosity value.

Since we have three unknown factors, we obtain the solution by data from three points in the spectrum. The following three equations are formed:

$$\begin{aligned} L_{\lambda 1} &= a_1 L_R + a_1' L_G + a_1'' L_B \\ L_{\lambda 2} &= a_2 L_R + a_2' L_G + a_2'' L_B \\ L_{\lambda 3} &= a_3 L_R + a_3' L_G + a_3'' L_B \end{aligned}$$

where $L_{\lambda 1}$, $L_{\lambda 2}$, and $L_{\lambda 3}$ are taken from the luminosity curve, the a's from the mixture curves, and L_R, L_G, and L_B are the coefficients to be determined.

Solving, we obtain:

$$L_R = \frac{-(a_1'a_2'' - a_2'a_1'')(L_{\lambda_1}a'_3 - L_{\lambda_3}a'_1) + (L_{\lambda_1}a_2'' - L_{\lambda_2}a_1'')(a'a_4'' - a_4'a_1'')}{(a_1a_2'' - a_2a_1'')(a_1'a_4'' - a_4'a_1'') - (a_1'a_2'' - a_2'a_1'')(a_1a_4'' - a_4a_1'')}$$

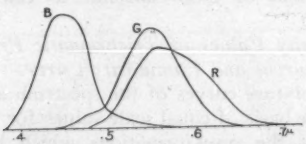
$$L_G = \frac{-(a'_2a''_3 - a'_3a''_2)(L_{\lambda_2}a_1'' - L_{\lambda_1}a_2'') + (L_{\lambda_2}a_3'' - L_{\lambda_3}a_2'')(a_2'a_1'' - a_1'a_2'')}{(a_2a_3'' - a_3a_2'')(a_2'a_1'' - a_1'a_2'') - (a_2'a_2'' - a_2'a_2'')(a_2a_1'' - a_1a_2'')} \quad (13)$$

$$L_B = \frac{-(a_3'a_1'' - a_1'a_3'')(L_{\lambda_3}a_2'' - L_{\lambda_2}a_3'') + (L_{\lambda_3}a_1'' - L_{\lambda_1}a_3'')(a_3'a_2'' - a_4'a_3'')}{(a_3a_1'' - a_1a_3'')(a_4'a_2'' - a_2'a_4'') - (a_4'a_1'' - a_1'a_2'')(a_3a_2'' - a_2a_3'')}$$

These various relations between the properties of the spectrum which have now been developed suffice for all the transformations from system to system which are ordinarily to be met with. In addition, as will be seen, they furnish criteria by which the accuracy of the determinations of spectrum mixture curves may be tested.

The Elementary and Fundamental Color Sensation Curves.—It has been pointed out that there are as many trichromatic sys-

FIG. 8.



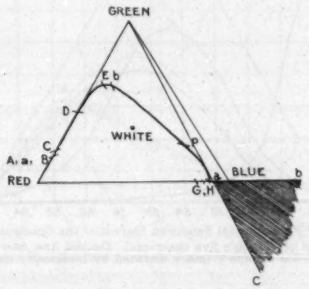
The Elementary Sensation Curves as Determined by Koenig for His Own Eye. These differ from the mixture curves in having no negative values.

tems of color measurement as there are possible choices of sets of red, green, and blue that will mix to make white. It has also been pointed out that the color-mixture curves of the spectrum, which is the purest hue scale obtainable, always have regions of negative values. These two facts have suggested, first, that the real primary "sensations" lie outside the spectrum, and, second, that these primary "sensations," if they can be determined, constitute the set of primaries to which all mixture data should be transformed. It is clear, from what has gone before, that a set of mixture data can be transformed to any other set of primaries. From the color-triangle plot of the spectrum, using any real primaries, as in Fig. 7, it is evident that we can choose a set of primaries lying outside the triangle such that the spectrum will lie entirely within the new triangle formed by joining the new primary points. When the data have been transformed

to this new set of primaries the corresponding color-mixture curves no longer have negative values. Curves constructed from the mixture data so as to have no negative regions have been called by Koenig "Elementary sensation curves." The elementary sensation curves found by Koenig for his own eye are shown in Fig. 8. (The sensation curves obtained by Abney are "Elementary" sensation curves.)

To this criterion for fundamental character Koenig then added another. A large number of selections of primaries is possible which shall give no negative values to the spectrum. What guide is there for the selection of the true fundamentals? This Koenig found from mixture measurements on color-blind

FIG. 9.



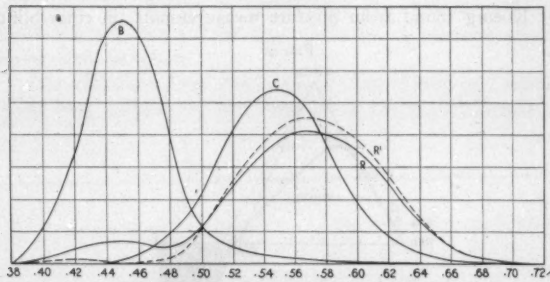
The Fundamental Sensations Represented in a Color Triangle.
Cross-hatched area is region within which blue primary may be chosen without conflict with the experimental data.

observers. By a certain choice of these possible primaries lying outside the spectrum it was found that the chief types of color-blindness reduced to absence of one or the other of these primaries. The final choice of primaries is shown by the color sensation triangle Fig. 9, in which the spectrum is plotted for reference. Fig. 10 shows the mixture curves of these primaries, or the "Fundamental sensation curves." (The mean values for Koenig's group of observers are plotted.)

Assuming the correctness of these curves, we have here the fundamental reference frame to which all color measurements are properly reduced. The methods for doing this have already been indicated. Spectrophotometric data are directly reducible

by the multiplication of ordinates. Three-color mixture data are reducible, once the sensation values of the primaries are known, and these are obtainable from spectrophotometric values. In order to determine the sensation values from measurements of hue, luminosity, and luminosity of white, it is necessary to know the luminosity values of the three sensations. These were not considered or measured by Koenig, but can be obtained by the methods given above. Their determination brings up points of some interest, to which a separate section will be devoted.

FIG. 10.



The Fundamental Sensation Curves of the Spectrum.
Full lines mean values of Koenig's five observers. Dashed line, new red curve, obtained by different choice of blue primary dictated by luminosity considerations.

THE LUMINOSITY VALUES OF THE KOENIG FUNDAMENTAL COLOR SENSATIONS.

In order to obtain the luminosity values of the fundamental sensation primaries, equations (12) were used, the coefficients at any wave-length being read off the sensation curves and the luminosities of the same wave-lengths off the luminosity curve of the white light spectrum. Two peculiarities were found in the values obtained: First, the values for the luminosities of the sensations are not constant, but differ with the wave-lengths used; and, second, the luminosity value of the blue sensation comes out *negative*. For instance, using wave-lengths 0.63μ, 0.50μ, and 0.46μ, the luminosity values are (in arbitrary units):

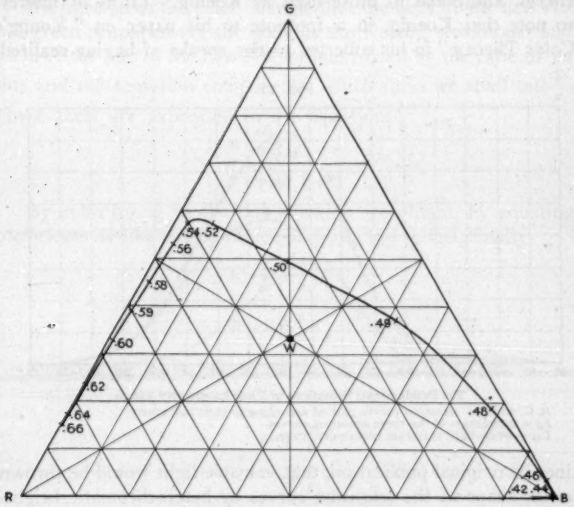
$$L_R = .395$$
$$L_G = .578$$
$$L_B = -.028$$

Using wave-lengths 0.60μ, 0.052μ, and 0.46μ, the luminosity values are:

$$L_R = .483$$
$$L_G = .491$$
$$L_B = -.026$$

The reason for these peculiarities is found, upon inspection of the sensation curves, to be due to the existence of the second

FIG. 11.



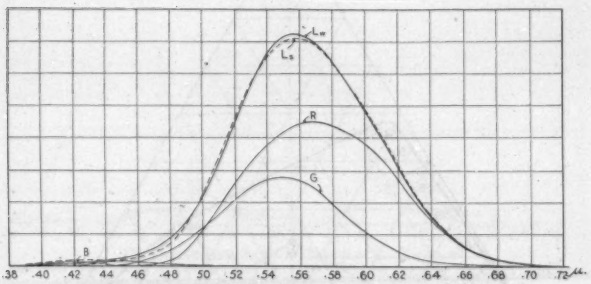
The Fundamental Color Sensation Triangle.
The new red curve is used in plotting this.

maximum of the red sensation in the blue of the spectrum. *This maximum as determined by Koenig is of such elevation that no positive luminosity values for the blue sensation will satisfy the conditions, at the same time that the red sensation is given adequate values to take care of the red end of the spectrum.*

This second maximum of the red sensation owes its existence to the fact that the blue primary was chosen quite far outside the spectrum, as is shown by the sensation color triangle. Now

the interesting thing is that this position was fixed upon, as Koenig says, "*völlig willkürlich.*" Fig. 9, reproduced from Koenig's original paper, shows the sensation equilateral triangle as adopted, but with the region indicated, by the cross-hatched area *abc*, within which the blue primary might be placed anywhere and still be in agreement with the experimental data. The assignment of luminosity values to the sensations actually constitutes a new criterion for the correctness of the fundamental curves, additional to those used by Koenig. (It is of interest to note that Koenig, in a footnote to his paper on "Young's Color Theory" in his collected works, speaks of having realized,

FIG. 12.



The Fundamental Sensations in Their Luminosity Values.

R, *G*, and *B* = sensation curves plotted according to their luminosity.
Ls = summation of the three sensation curves.
L_W = white light spectrum luminosity curve.

since its original publication, that valuable light would be thrown on the shape of the sensation curves by heterochromatic brightness equations.)

The failure of Koenig's curves to yield consistent luminosity values in their present form suggests the desirability of re-plotting his data with a different choice of the wholly arbitrary factor —the blue primary—such that this new criterion will be satisfactorily met. Any point between *b* and *a* in Fig. 9 may be tried, but the very low luminosity of this part of the spectrum suggests the point *a* itself as the most probable. The transformation to a new set of primaries, comprising the old red and green and the new blue defined by the point *a*, follows, being

merely a special case of the transformation methods already described.

Let the coefficients of any wave-length on the Koenig curves be a, a', a'', and let the new unknown coefficients be x, y, and z. Then we have

$$aR + a'G + a''B = xR + yG + zB$$

We have also, since both systems are referred to the same white, $R' + G' + B' = R + G + B$.

We have from the color triangle that the hues of the new red and green primaries are the same as the Koenig sensations; and we have the hue of the new blue primary fixed by the ratio of its blue and red sensation components, which ratio we shall call $\frac{b}{c}$. These facts are expressed in the equations:

$$\begin{aligned} R' &= mR \\ G' &= nG \\ B' &= p(bB + cR) \end{aligned}$$

By substituting in the last equation we obtain, by equating coefficients of like terms, values of m, n, and p, and, finally,

$$\begin{aligned} R' &= \left(1 - \frac{c}{b}\right)R \\ G' &= G \\ B' &= B + \frac{c}{b}R \end{aligned}$$

Substituting in the first equation for R', G', B' we get

$$\begin{aligned} y &= a' \\ z &= a'' \\ x &= \frac{a - a''\frac{c}{b}}{1 - \frac{c}{b}} \end{aligned}$$

This gives us the final relation that any color represented in the Koenig curves by the expression

$$aR + a'G + a''B$$

is given in the new system by the expression

$$\frac{a - a''\frac{c}{b}}{1 - \frac{c}{b}}R' + a'G' + a''B' \qquad (14)$$

The only coefficient which is changed by this particular transformation is that of the red curve points.

The value of $\frac{c}{b}$ to be used was obtained by drawing the line from the green vertex of the sensation triangle through the point nearest the green-blue side obtained by the mean of Koenig's group of observers. From its intersection on the red-blue line the value for $\frac{c}{b}$ is 0.092, giving a working value of $\frac{a-.092a''}{.908}$ for the new red coefficient.

In Fig. 10 are shown the Koenig sensation curves, plotting the mean values of all his observers, and the new red curve, obtained from these by the transformation just indicated. In Fig. 11 the spectrum is shown in the new color triangle.

The new curves should meet the additional criterion that consistent luminosity values may be assigned them. This point was tested by solving equations with three sets of three wave-lengths. These gave positive and fairly consistent values for the luminosities of the three sensation primaries. Assigning to each the mean value obtained, the three curves were plotted, their summation made and compared with the luminosity curve of the white light spectrum. Some changes were then made to make the agreement best in the best-determined and most important parts of the luminosity curve, giving as the final values,

Luminosity of red sensation	.648
Luminosity of green sensation	.336
Luminosity of blue sensation	.016

In Fig. 12 are shown the three new sensation curves in their luminosity values, their summation, and the white light luminosity curve.

Remembering that different groups of individuals determined the various curves which are compared, that the variations among the observers of the sensation curves are quite large, and that various assumptions have been made, such as the energy distribution in white light, it is evident that the agreement is quite good. It certainly lies within the uncertainty of determination of both sensation and luminosity curves. These luminosity values are very nearly the same as those assigned by Abney to his elementary sensations, which gives some additional weight.

The subject matter of this section may be summarized as to

its practical and theoretical results. On the practical side luminosity values have been found for the fundamental sensation primaries, completing the necessary data for the transformation of all practical color measurements to sensation values, and *vice versa*. On the theoretical side an additional condition which must be met by sensation curves has been applied to the Koenig curves, resulting in a slight modification of their form.

With regard to the position of the blue primary, which was left undetermined by Koenig's two criteria, the luminosity criterion, of course, fixes only the region within which the luminosity value shall be positive, consequently the true position is still somewhat in doubt. Probably the only means of fixing this exactly would be the isolation and study of the optical properties of the "red" photochemical substance of the retina, as Koenig has suggested.

SOME NUMERICAL EXAMPLES OF COLOR EQUATION TRANSFORMATIONS.

Color measurements of the same colors made by both the trichromatic and monochromatic methods, suitable for illustrating the use of equations (10) and (11), are few. The only measurements known to the writer which can be used are some upon illuminants, the monochromatic by Jones,[4] the trichromatic by the writer.[8] The latter, reduced to Koenig sensation values, are referred to a black body at 5000° as white, the former to clear sunlight. A number of accurately specified light sources which occur in both sets of data have accordingly been transformed from one system to the other by the equations quoted.

Taking for illustration the tungsten lamp at 1.25 w. p. c., this was found, through the trichromatic measurements, to have Koenig sensation values:

$$R = .479$$
$$G = .411$$
$$B = .110$$

These were transformed to the revised Koenig values by the relation 13, giving

$$R = .502$$
$$G = .393$$
$$B = .105$$

The spectrum hue from the color triangle is 0.586μ. The color triangle coefficients of this wave-length are

$$\begin{aligned} u &= .570 \\ v &= .415 \\ w &= .015 \end{aligned}$$

From relations 9 and 10 we obtain

$$\begin{aligned} L'_C &= .459 \\ L'_W &= .103 \\ \frac{L'_W}{L'_C} &= .224 \end{aligned}$$

(We note that in the case of measurements of illuminants we obtain only the *relative* values of the three colors mixed or the *ratio* of the color and white constituent luminosities, represented as before, by primed letters.) The corresponding values for the tungsten lamp as obtained by Jones's monochromatic measurements are

$$\begin{aligned} \text{hue} &= .588\mu \\ \frac{L'_W}{L'_C} &= .35 \end{aligned}$$

Now, taking Jones's monochromatic readings and applying relation 11, we obtain relative values for the three sensations, which when reduced to the same summed value as those obtained by the other method are

$$\begin{aligned} R &= .472 \\ G &= .371 \\ B &= .157 \end{aligned}$$

This comparison was made upon several of the tabulated illuminants, with the result that the hue, as derived from the trichromatic measurements, was always quite close to the directly measured values, but the luminosity values were considerably different. Upon obtaining the sensation values from the monochromatic measurements and plotting them in the same color triangle with the trichromatic measurements, the transformed monochromatic ones were found to be *uniformly shifted toward the blue corner of the triangle.*

These differences between the two sets of measurements when reduced to the same terms find a possible explanation in a difference between the whites to which the measurements were referred. If, for example, Jones's measurements are expressed in

terms of a point removed from the centre of the triangle a short distance toward the blue (that is, are referred to a bluer "white"), the greater part of the differences in the sensation values disappear. His values lie, in fact, between those the writer obtained [4] in an investigation using an average daylight as determined by Nichols, which is probably too yellow for a true average, and the values based on the 5000° black body, which has been thought to represent clear noon sunlight, or "average daylight" satisfactorily.

Obviously a complete test of these equations of transformation can be made only by comparing measurements by the two methods which have been made in terms of the same white. Assuming the essential correctness of the equations and the constants employed and the substantial similarity of the color vision of the two observers, the differences between the two sets of data under comparison form a valid indication of the different whites employed in the two cases. On the other hand, some recently published comparisons of spectrophotometric values, at three points in the spectrum, with three-color mixture values, obtained in another country, do not without elaborate transformations furnish any such information.[6]

GENERAL REMARKS ON COLOR MEASUREMENT.

In this paper have been gathered together or developed those data necessary for the transformation of three-color mixture measurements from one set of primaries to another, and for the transformation of hue, luminosity, and saturation measurements to three-color units, and *vice versa*. The fundamental color sensations have been emphasized as the units in which all color measurements should be expressed. The experimental values obtained by Koenig for these sensations (as distributed in the spectrum) have been used to form slightly modified values, which are now available for the numerical description of color in the simplest possible terms.

It is the writer's hope that this work will help to clear up some obscure points and misunderstandings on the subject of color measurement, and so bring the problem nearer to satisfactory solution. It is well, however, to point out that color measurement is simpler in theory than in practice, for a number of

reasons. We have, first and foremost, to contend with the difference in color vision between different observers. Anything except an exact spectral match, wave-length by wave-length, fails to be an integral color match with individuals of different color vision. Both the practical methods of color measurement suffer from this limitation, since they both provide merely subjective matches. This difficulty can be met only by the careful selection of a group of observers who shall meet some vision test, as yet unspecified. But even with this precaution there are serious difficulties, prominent among which is the fact that the technical requirements for precision are altogether too severe for any present optical instrument to meet. The comparison of juxtaposed surfaces without the intervention of any instrument represents the condition under which the eye is at its maximum sensibility for the discrimination of small color differences. Colors which will measure up alike by instrumental means (which themselves are dependent on the eye) will frequently fail by the test of simple side-by-side comparison.

A difficulty standing in the way of the practical use of some of the transformations dealt with here is the lack of a standard artificial reproducible white light—a deficiency which may be met by the adoption of an instrument recently constructed for the spectroscopic synthesis of colors.[7] The difficulties in the way of measuring colored light luminosities have been hinted at. The most promising means of meeting them appears to the writer to be the development of physical photometers which shall incorporate the characteristics of the average eye. The measurement and specification of color may also find its ultimate practical solution in the development of a sensitive physical artificial eye, such as that recently described by the writer.[8] Where great accuracy is necessary, however, it is very questionable whether either of the three element methods of analysis will ever be satisfactory, beautifully simple though they are in theory.

A spectrophotometric table, derived from at least 25 points (for a continuous spectrum), gives the only unique description of a color, and it appears probable to the writer that the requirements of precision technical color measurement are most likely to be met by the development of simple and rapid means of plotting and recording accurate spectrum plots of reflection or transmission characteristics. But for descriptive purposes, where

great accuracy is not imperative, the three-element systems are excellent when properly used.

Physical Laboratory, United Gas Improvement Company,
Philadelphia, July 23, 1915.

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Printing Three Colors at One Impression. ANON. (*The Engraver and Electrotyper*, October, 1915.)—A machine to print the three primary colors at one impression, which may effect a considerable saving in the cost of printing, though not in the cost of the plates, has been invented by T. R. Johnston, of Japan. According to the inventor, this machine will produce prints in three colors on small sheets in less time than the machines in general use will print one color on large sheets.

On the form bed are placed, side by side, the three blocks or chases for the yellow, red, and blue printings. The ink duct is divided so as to supply these colors to different portions of the inking rollers which respectively cover their blocks. The press can be either the stop-cylinder or the two-revolution type.

There are three sheets on the cylinder at one time: the first, receiving its yellow impression; the second, having already had its yellow impression, receiving its red impression; and the third, hav-

ing already had its yellow and red impressions, receiving its blue impression.

A sheet being fed to the cylinder grippers first receives its yellow impression, and then when the cylinder is stationary, as it will be if of the stop-cylinder type, or when it is making its second revolution, if of the two-revolution type, the sheet moves along the cylinder's surface so that at the cylinder's next revolution it receives a second impression from the red block. After receiving this impression it again moves along the cylinder's surface and receives its blue impression, after which it is removed to the delivery apparatus. Consequently at every revolution of the cylinder a sheet is produced in three colors.

By this invention, once a sheet is taken by the cylinder grippers it is retained by them until the printing is completed and correct register is therefore insured. With the exception of the printing blocks, nothing touches the faces of the sheets from the time they are fed in until they are delivered face upwards.

There are several advantages in this method of printing, one being that, as the colors are printed immediately after each other, there is not time for the atmosphere to act on the paper and alter its size, this alteration causing a great deal of trouble in the securing of register when one color is printed at a time and an interval elapses before another color is applied to the sheets. Another advantage is that the inking and distributing rollers and ink duct have to be cleaned only once for all three colors.

Aërodynamical Experiments upon a Yacht's Mainsail. H. A. EVERETT. (*Proceedings Society of Naval Architects and Marine Engineers,* November 18 and 19, 1915.)—Primarily designed for the investigation of problems in aërial navigation, the aërodynamical laboratory is proving of value in the older art of the design of ships' sails. By means of the "wind tunnel" of the Aëronautical Laboratory of the Massachusetts Institute of Technology experiments have been made upon a model sail to determine the true centre of pressure, the normal pressure per unit of area for a given wind velocity, and the proper angle of boom to centre line for fastest sailing over a given course. The "wind tunnel" consists essentially of a square duct, 4 feet on a side, through which a current of air is drawn at uniform velocity with a balance under it which supports the models to be tested and weighs the forces acting on them.

The experiments were carried out with a model of the mainsail of a racing yacht made to a scale of ⅜ inch to 1 foot. Among the other results of the experiments it was shown that for courses from 45° to 160° with the apparent wind (shown by the fly at the masthead) the angle between the boom and the centre line of the ship for best sailing with this sail should be approximately one-half the angle between the fly at the masthead and the centre line of the ship.

ON THE BOILING-POINT OF AQUEOUS SOLUTIONS OF NITRIC ACID AT DIFFERENT PRESSURES. PART II.—THE INFLUENCE OF WATER-RETAINING AGENTS ON THE COMPOSITION OF THE MIXTURE OF MAXIMUM BOILING-POINT.*

BY

HENRY JERMAIN MAUDE CREIGHTON,

Member of the Institute,

AND

HERSCHEL GASTON SMITH,

Department of Chemistry, Swarthmore College.

In a previous investigation[1] it was found that the composition of the mixture of maximum boiling-point formed by nitric acid and water changes but slightly with pressure, varying from 66.80 per cent. of nitric acid at 110 mm. pressure to 68.18 per cent. of acid at 760 mm. pressure. These results indicate that the content of nitric acid in the mixture of maximum boiling-point increases slowly as the pressure is raised. It was hoped to continue the investigation at higher pressures, but, since preliminary experiments indicated that at high pressures the nitric acid undergoes considerable decomposition when its aqueous solutions are heated to their boiling-points, it was deemed advisable first to study the influence of the presence of certain non-volatile water-retaining agents on the composition of the mixture of maximum boiling-point.

In the following experiments sulphuric acid and anhydrous potassium acid sulphate have been employed as water-retaining agents.

The apparatus, procedure, and precautions employed in this investigation are essentially the same as those recorded in Part I. Further precautions have been used to prevent a temporary cooling of the bulb of the thermometer by liquid condensing on its sides. This has been accomplished by catching the descending

* Communicated by Professor Creighton.

[1] Creighton, H. J. M., and J. H. Githens, JOURNAL OF THE FRANKLIN INSTITUTE, 179, 161 (1915).

liquid some distance above the bulb of the thermometer, and leading it away to the inside of the thin-walled tube surrounding the thermometer. In order to achieve this, a piece of glass tubing about 2 cm. long, with an internal diameter about 2 mm. greater than the diameter of the thermometer, was placed around the latter at a distance of 70 mm. above the bulb, and the space between the glass ring and the thermometer was packed with asbestos. The upper edge of the ring was slightly bevelled so as to permit easy packing with the asbestos, and at the bottom two flutes, or spouts, were made to carry off the liquid which passed down through the asbestos. The ring was held in position by wrapping a piece of platinum wire around the thermometer below the lower edge of the ring. Two views of the ring and thermometer are shown in Fig. 1. The arrangement just described was found to be very effective and entirely prevented any cooling of the thermometer by the condensed liquid.

From the values obtained at atmospheric pressure the boiling-points at 760 mm. were calculated.[2] In all determinations of the boiling-point the thermometer readings were corrected for the cooling of the mercury thread which extended above the neck of the flask in which the liquid was boiled.[3] The aqueous solutions of nitric acid were heated to boiling, and, after the boiling-point became constant, the liquid remaining in the flask was quickly cooled and its content of nitric acid determined with standard barium hydroxide, phenolphthalein being used as indicator.

Determinations of the boiling-points of aqueous mixtures of nitric acid have been carried out, at 760 mm. pressure, in the presence of 10 and 20 per cent. of anhydrous potassium acid sulphate; and at 760, 360, and 200 mm. pressure, in the presence of 10 and 20 per cent. sulphuric acid. The results of these determinations are recorded in Tables I, II, and III. The percentages of nitric acid given in these tables refer to a dehydrating-agent-free solution, the weight of the dehydrating agent having been deducted in calculating the nitric acid content. Isobaric curves showing the change in the boiling-point with variation in the composition of the mixture are shown in Fig. 2 and Fig. 3. For the purpose of comparison, curves showing

[2] Kahlbaum, G. W. A., *Ber.*, 19, 3101 (1886).
[3] Rimbach, E., *Ber.*, 22, 3072 (1889).

FIG. 1.

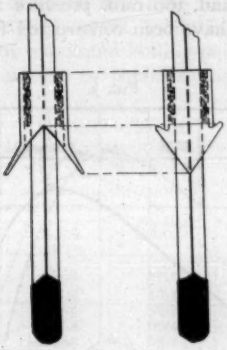
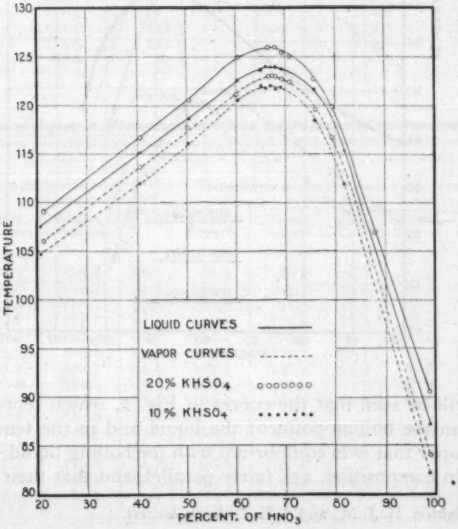
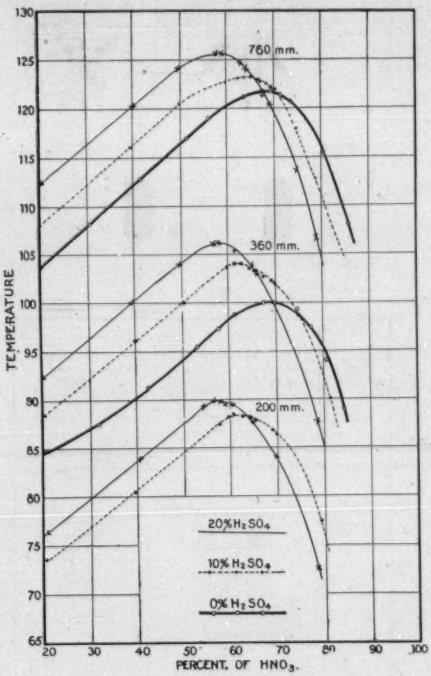


FIG. 2.


TEMPERATURE
PERCENT. OF HNO_3
LIQUID CURVES
VAPOR CURVES
20% $KHSO_4$
10% $KHSO_4$
130
125
120
115
110
105
100
95
90
85
80
20
30
40
50
60
70
80
90
100

the change in the boiling-point of pure, aqueous solutions of nitric acid at 760 and 360 mm. pressure are given in Fig. 3. These latter curves have been constructed from data previously obtained.[4]

FIG. 3.



It will be seen that the curves in Fig. 2, which represent the change in the boiling-point of the liquid and in the temperature of the vapor that is in equilibrium with the boiling liquid, with variation in composition, are fairly parallel, and that their shape is

[4] Creighton, H. J. M., and J. H. Githens, *loc. cit.*

characteristic of a mixture of maximum boiling-point. Furthermore, it will be observed that little or no displacement of the maxima of the curves occurs, indicating that the composition of the mixture of maximum boiling-point remains constant with increase in the amount of potassium acid sulphate present.

TABLE I.

PRESSURE=760 mm.

Boiling-point of Aqueous Mixtures of HNO_3 in the Presence of:

10 per cent. $KHSO_4$			20 per cent. $KHSO_4$		
Per cent. HNO_3	Temperature of:		Per cent. HNO_3	Temperature of:	
	Liquid, degrees	Vapor, degrees		Liquid, degrees	Vapor, degrees
20.5	107.5	104.8	21.1	109.1	106.1
40.4	115.0	111.9	40.4	116.6	113.6
50.3	118.6	116.1	50.2	120.6	117.8
60.3	122.5	120.5	60.4	124.9	121.1
65.0	123.6	122.1	65.2	126.0	122.7
66.0	123.9	121.7	66.4	126.0	123.1
67.0	124.0	122.0	67.1	126.1	123.4
68.2	124.0	121.6	68.0	126.0	123.2
69.3	123.7	121.8	69.3	125.5	122.7
....	.....	.....	70.8	124.9	122.5
75.7	121.7	118.5	75.4	122.7	119.6
81.7	115.3	111.7	79.3	119.8	116.8
99.0	87.2	82.2	99.1	90.6	84.1

TABLE II.

Boiling-point of Aqueous Mixtures of HNO_3 in the Presence of 10 Per Cent. H_2SO_4.

Pressure = 760 mm.			Pressure = 360 mm.			Pressure = 200 mm.		
Per cent. HNO_3	Temperature of:		Per cent. HNO_3	Temperature of:		Per cent. HNO_3	Temperature of:	
	Liquid, degrees	Vapor, degrees		Liquid, degrees	Vapor, degrees		Liquid, degrees	Vapor, degrees
20.2	108.0	105.8	20.5	88.5	86.2	20.5	73.5	71.5
39.6	116.0	114.2	39.8	96.0	94.4	39.6	80.4	79.4
49.7	120.5	118.4	50.3	100.0	98.3	57.5	87.5	85.9
59.7	122.6	121.1	59.5	103.6	102.0	59.5	88.2	86.7
62.6	123.1	122.4	61.0	104.2	102.5	60.5	88.6	87.1
63.8	123.2	122.6	62.7	103.9	102.2	62.7	88.3	86.9
65.1	123.2	122.5	64.4	103.4	102.1	64.3	88.2	86.6
66.7	123.0	122.4	65.2	103.3	102.0	65.3	87.8	86.2
67.2	122.8	121.9	67.3	102.7	101.5	66.9	87.5	85.8
68.5	122.6	120.9	....	.....	.....	....	....	....
69.1	122.1	120.5	69.0	102.2	101.0	69.2	87.0	85.5
70.2	122.1	120.6	69.7	101.9	100.4	69.7	86.5	85.1
74.4	117.8	116.6	74.7	98.8	97.0	....	....	....
78.8	112.8	110.2	81.3	90.1	87.3	79.3	77.5	74.4
97.7	85.7	83.7	....	.....	.....	....	.....	....

TABLE III.

Boiling-point of Aqueous Mixtures of HNO_3 in the Presence of 20 Per Cent. H_2SO_4.

Pressure = 760 mm.			Pressure = 360 mm.			Pressure = 200 mm.		
Per cent. HNO_3	Temperature of:		Per cent. HNO_3	Temperature of:		Per cent. HNO_3	Temperature of:	
	Liquid, degrees	Vapor, degrees		Liquid, degrees	Vapor, degrees		Liquid, degrees	Vapor, degrees
20.1	112.2	109.3	19.9	92.2	88.7	20.5	76.3	74.4
40.2	120.1	117.4	39.6	100.3	97.8	40.4	84.1	81.8
49.5	124.3	122.5	49.7	103.8	101.3	54.2	89.3	86.7
57.8	125.4	123.1	56.8	105.8	103.3	56.5	89.9	86.7
59.2	125.6	123.6	58.2	106.2	103.0	57.9	89.9	86.8
61.8	124.3	123.3	59.3	105.3	103.3	58.8	89.5	86.5
62.7	124.1	122.6	60.9	105.1	102.9	60.6	89.5	86.4
64.1	123.9	121.9	64.4	103.7	100.5	62.7	88.6	86.3
67.5	121.3	118.8	65.7	102.9	99.2	64.5	87.7	85.3
69.1	120.4	117.8	69.5	100.2	96.1	69.5	84.2	80.8
74.8	113.4	109.5	....	.....	.....	....	....	....
78.8	106.8	101.0	78.4	87.7	82.8	78.4	72.6	67.0
97.1	87.9	83.9	98.6	68.7	65.5	....	....	....

The curves in Fig. 3, which represent the change in the boiling-point of aqueous solutions of nitric acid, in the presence of different amounts of sulphuric acid, with variation in composition, are also fairly parallel, and their shape is characteristic of a mixture of maximum boiling-point. Examination of these curves shows that, for a given pressure, the boiling-point is increased and the position of the maxima is appreciably displaced in the direction associated with a decrease in the nitric acid content of the mixture of maximum boiling-point, as the amount of sulphuric acid present is increased. At 760 mm. pressure the position of the maxima corresponds to the following amounts of nitric acid in the mixture of maximum boiling-point: 68.18 per cent. when no sulphuric acid is present, 64.5 per cent. in the presence of 10 per cent. sulphuric acid, and 59.2 per cent. in the presence of 20 per cent. sulphuric acid. It will further be observed that the position of the maxima is displaced slightly towards the left as the pressure is decreased.

The results of this investigation show that, although the boiling-point of the mixture of maximum boiling-point is raised by the presence of additions of potassium acid sulphate, the elevation of the boiling-point is not attended with any appreciable change in the composition of the mixture of maximum boiling-point. On the other hand, additions of sulphuric acid to aqueous solu-

tions of nitric bring about a material change in the composition of the mixture of the maximum boiling-point, and these changes are further slightly increased as the pressure at which boiling takes place is lowered. These results show clearly why 68 to 69 per cent. aqueous solutions of nitric acid (mixture of maximum boiling-point) can be concentrated to over 90 per cent. by distillation with concentrated sulphuric acid; and they indicate that still better results would be obtained if the distillation were carried out at diminished pressure. On the other hand, potassium acid sulphate would be of little or no use in concentrating aqueous solutions of nitric acid.

SUMMARY.

1. The influence of the presence of potassium acid sulphate and sulphuric acid on the boiling-points of aqueous solutions of nitric acid has been studied at atmospheric and diminished pressures.

2. It has been found that, while the presence of potassium acid sulphate brings about little or no change in the composition of the mixture of maximum boiling-point, additions of sulphuric acid to aqueous solutions of nitric acid cause a decrease in the nitric acid content of the mixture of maximum boiling-point, the decrease being greater the greater the addition of sulphuric acid.

3. Diminishing the pressure has also been found to cause a slight further decrease in the nitric acid content of the mixture of maximum boiling-point.

4. The results obtained show clearly why aqueous solutions of nitric acid can be concentrated to over 90 per cent. by distillation with concentrated sulphuric acid.

Chemical Laboratory, Swarthmore College,
Swarthmore, Pa., October 25, 1915.

Variation of Frictional Resistance of Ships with Condition of Wetted Surface. W. MCENTEE. (*Proceedings Society of Naval Architects and Marine Engineers,* November 18 and 19, 1915.)—Considering that frictional resistance is the most important element in the resistance of practically all ships, it is noteworthy that investigations of conditions affecting it have been relatively few. At various times attempts have been made to reduce the frictional re-

sistance of ships by lubricating the under-water surface or by polishing to a high degree with various materials. One favored method used for racing yachts is to polish the bottom with black lead or graphite.

An investigation of the benefits to be expected from such polishing or lubrication has recently been made at the Model Basin of the United States Navy with friction planes. These planes are of wood, roughly 20 feet by 2 feet by ¾ inch, with ends sloped forward at an angle of about 30 degrees. The total wetted surface for each is about 82 square feet.

Trials were made with planes coated with shellac, black lead, ivory soap, heavy cylinder oil, and light cylinder oil. The results of the experiments indicate that no advantage over a smooth varnish on shellacked surface is obtained with the materials used. For each lubricating surface the resistance is greater than for the shellacked surface. The resistance increases in the following order: black lead, light engine oil, ivory soap, heavy cylinder oil. The black lead, although yielding a result nearly as low as the shellac, is easily rubbed off when the surface is wetted.

Solving the Potash Problem. ANON. (*United States Commerce Reports,* No. 25, October 28, 1915.)—Several new methods of increasing the supply of American potash have recently been brought to the attention of the Bureau of Foreign and Domestic Commerce. One of the most promising of these efforts to find a substitute for German fertilizers is a patent taken out a few weeks ago by a Canadian for a method of using the potash in ordinary feldspar.

The process is a simple one, consisting of heating the feldspar with limestone and iron oxide at a temperature of about 2200° F., which produces a partly-fused mass that is easily decomposed by a weak acid. From this product the potash salts can readily be extracted for further purification. The inventor has been in consultation with Dr. Norton, the expert, who has been looking after the potash and dyestuff situations for the Bureau of Foreign and Domestic Commerce, and it seems very possible that a greatly-simplified method of transforming feldspar into fertilizer will soon be available.

A practical try-out for another method of obtaining potash fertilizer will soon take place at a New Orleans distillery where molasses is used in large quantities. It is a fact that 106 tons of potash are wasted daily by the 25 or more distilleries in this country that subject molasses to processes of fermentation. The New Orleans company is planning to install the process of saving the potash in distillery waste recently brought to the attention of the public by the Bureau of Foreign and Domestic Commerce. It should be possible to make fertilizer from this otherwise worthless material at a price that will meet competition even after the war is over.

THE PRODUCTION OF LIGHT BY ANIMALS*.

BY

ULRIC DAHLGREN,

Professor of Biology, Princeton University.

Several groups of unicellular organisms other than the bacteria are capable of luminosity. There are the *Dinoflagellata* and the *Cystoflagellata* of the class *Flagellata* or *Mastigophera* of Protozoa, also the *Radiolaria* of the class *Sarcodina*.

When we look over the large phylum of the protozoa as classified by the various authorities, and scan the lists of luminous forms so far known, we are struck by the fact that only those that are found in salt water are light producers. Furthermore, these light producers are almost limited to strictly pelagic forms that live on the surface of the sea and are known as plankton forms.

The forms that can produce light are homogeneous pelagic groups whose members appear to be highly specialized and to have had their origin as well as passed their phylogenetic history on the surface of the sea. They have, apparently, been thus continuously influenced by the unknown factors of this pelagic life that results in the specialization of the light-producing power in so many other organisms that have this same habitat. The Radiolarians and Cystoflagellates are such kinds of protozoa.

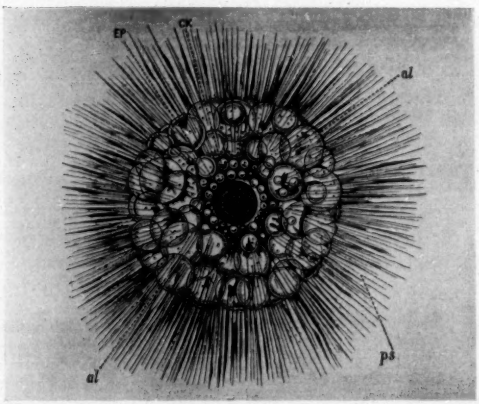
Not all plankton protozoa, however, can produce light. We find a number of kinds in which the power is not developed, although they are found in the marine plankton. Some of these are, evidently, recently adapted to the life and come from groups that are principally found in the fresh waters of the earth. Perhaps in this case they have not existed in salt water long enough to have developed the power. Other pelagic forms appear to have no luminous members, although they are largely found in salt water, and from their numbers and variety seem to have originated there.

The Radiolarians are a group of protozoa in which the light-producing power has been well observed, especially in the colonial forms and also in the simpler or single-celled forms.

* Continued from page 537, November issue.

As far back as 1803, Tilesius mentioned the luminosity of a species of Radiolarian, probably the common form Thalassicola found in the Mediterranean Sea (Fig. 1). Others who mentioned Radiolarians as light-giving were W. Baird, Meyen, Giglioli, Meyer, and MacDonald. Brandt, in his monograph on the colonial Radiolarians in the "Flora und Fauna des Golfes von Neapels," first made careful experiments and observations on these forms and proved that they had the power to produce light.

FIG. 1.



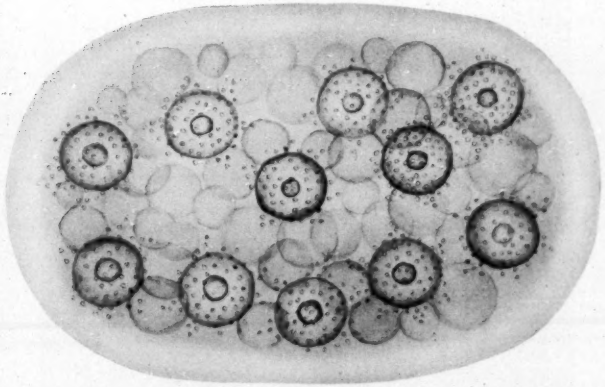
Thalassicola (*Thalassophysa*) *pelagica*. Haeckel. × 25. *CK*, central capsule; *EP*, extracapsular protoplasm; *al*, alveoli, carbonic acid-holding vacuoles in the mucilaginous calymma secreted by the protoplasmic network; *ps*, pseudopodia. The minute unlettered dots are the "yellow cells." (After Lankester.)

He studied especially the colonial forms, of which *Collozoum inerme* is a good example (Fig. 2).

He filtered a quantity of fresh sea-water into a glass vessel so as to exclude all other organisms that might possibly be present, and carefully placed about twenty living specimens of *Myxosphæra cærulea* in this water, which was then placed in a quiet, dark room at about the temperature of the sea. After allowing the experiment to rest for several hours he observed that no light was given off by it. He then moved the water in the glass

gently, and the mechanical stimulation caused the organisms to show a weak light. When the water was shaken somewhat more violently the *Myxosphœra* as well as *Collozoum* and other forms glowed brightly as little balls of light with a perceptible aurea (Fig. 3). The exact color of this light was not mentioned. The observer then turned on artificial lights in the room and made sure that the balls of light were in reality the animals he had put into the water, and that no other creatures were present

FIG. 2.



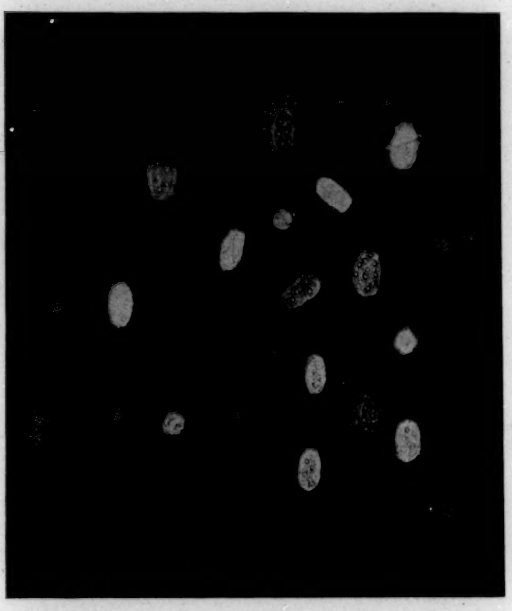
General view of a colonial radiolarian, *Collozoum inerme*, as seen under the microscope by transmitted light. It consists of a mass of jelly in which are numerous rounded spaces or vacuoles. Among these vacuoles are seen twelve "nests" or individual colonies, each with a large, round oil droplet in its centre. Around each "nest" are the swarm of the "yellow cells" or symbiotic algæ that live in the radiolarian. Nuclei, etc., are not seen in this figure. To understand the cell structure of these colonies see Fig. 4. (After Brandt.)

—an important measure in identifying any organism as the source of a light.

Several other interesting observations were made. When the animals had been made to light for some time by such mechanical stimulation it was found that they became incapable of further luminosity, and that the light died out entirely. This fact was taken to mean that they had used up some material that must be secreted and stored before being used to produce light; for all other conditions remained the same, especially the supply of free O_2 in the sea-water necessary for light production.

In order to confirm this conclusion the experimenter allowed the animals to rest quietly in this sea-water for from one to two hours. During this time they remained dark, but at the end of the period, when shaken again, they glowed a second time, which

FIG. 3.



Drawing representing six adult colonies of *Collozoum inerme*, to show their appearance when shining in the dark as described by Brandt for *Myxosphæra cærula*, *Collozoum inerme*, and other forms of colonial radiolarians. The light emanates from the region around the oil globule in each colony, giving each colony its own marked halo and the entire colony a halo that makes it appear as a ball of weak light. (Original drawing by E. Grace White after Brandt's description.)

was taken to show that they had secreted a new supply of the material during their rest.

Another experiment with the same animals was then tried. Fresh water was thrown on them, and the resulting light was even brighter than when they were shaken. Also when ammonia was

put in the water an even brighter light was produced. These two stimuli, of course, killed the protozoa in a few seconds, when the light was ended for all time. It was noticed that even when the light production was exhausted by mechanical stimulation still some more could be produced by chemical means, showing that an element of fatigue was present as well as an exhaustion of the luciferine. This fatigue may be interpreted as an inability of the organism to bring O_2 into contact with a small residue of luciferine.

In this connection it must be remembered that the strength of the luminosity is in proportion to the strength of the mechanical stimulus up to a certain point at which the supply of luciferine begins to diminish toward a vanishing point which is probably never reached. *Thalassicola nucleata* lighted in fresh water for fifteen to twenty minutes before dying.

Brandt also experimented with other forms of *Radiolarians*, as *Thalassicola nucleata, Collozoum inerme, Collosphæra huxleyi, Sphærozoum neapolitanum,* and *Sphærozoum punctatum,* and found that all of them reacted in a similar way. He did not study the physical characters of the light except to say that it was weaker than in other organisms, nor did he compare the kinds of light emitted by the different forms with each other. He did not study the influence of sunlight on the light production of the various forms.

Brandt also studied the structure of the *Radiolarians* with reference to any substance which might be the luciferine. He described the well-known "oil droplets," and gave it as his opinion that they were the seat of the luminosity.

In order to discuss this question the reader is referred to Fig. 2, which represents an adult colony of *Collozoum inerme.* Here it will be seen that the body of the organism or colony is a mass of jelly in which are imbedded a number (about 250) of the members or individuals of the colony. Each of these members (Fig. 4) consists of a round, multinucleated cell, in the centre of which is an oil droplet. The cytoplasm of this individual or "nest," as it is sometimes called, is divided into a larger central mass and a lesser outer zone which are separated from one another by the central capsule. The nuclei are placed in the peripheral part of the central mass, outside of and around the very large oil droplet.

No.	Name	Source	Morphology										B
			Bacillus	Spirillum	United in chains	Motile	Flagella	Spores	Capsules	Stains easily	Stains by Gram's		Turbidity
	Bacillus Pflugeri group:												
1	Bacillus annularis Fischer.....	Sea-water	+	−	−	+	+	−			−		+
2	Bacillus coronatus Fischer.....	Sea-water	+	−	−	+	+	−		−	−		+
3	Bacillus degeherins Fischer.....	Sea-water	+	−	−	+	+	−		−	−		+
4	Bacillus Fischeri Bey.....	Sea-water	+	−	−	+	+	−			−		+
5	Bacillus hirsutus Fischer.....	Fish and sea-water	+	−	−	+	+	−		+	−		+
6	Bacillus pflugeri Lud.....	Fish	+	−	−	+	+	−			−		
7	Bacillus phosphorescens Fischer...	Fish and sea-water	+	−	−	+	+	−			−		
8	Bacillus tuberosus Fischer.....	Sea-water	+	−	−	+	+	−		+	−		
9	Bacillus from meat, Gorham.....	Meat	+	−	−	+	+	−	+	−	−		
10	Bacillus indicum Fischer.....	Sea-water	+	−	−	+	+	−		−	−		
11	Bacillus balticus Bey.....	Sea-water	+	−	−	+	+	−		+	−		
12	Bacillus phosphoricus Mig.....	Fish and sea-water	+	−	−	+	+	−			−		
13	Bacillus argenteo-phosphorescens Mig.....	Fish and sea-water	+	−	−	+	+	−		+	−		
14	Bacillus plymouthii.....	Sea-water	+	−	−	+	+	−		+	−		
	Microspira luminosa group:												
15	Microspira caraibica Fischer.....	Sea-water	−	+	−	+	+	−		+	−		
16	Microspira glutinosa Fischer.....	Sea-water	−	+	−	+	+	−		+	−		
17	Microspira javaneasis Eij.....	Fish	−	+	−	+	+	−		+	−		
18	Microspira luminosa Bey.....	Fish and sea-water	−	+	−	+	+	−			−		
19	Microspira dunbari Mig.....	Sea-water	−	+	−	+	+	−		+	−		
20	Microspira from sea-water, Gorham	Fish and sea-water	−	+	−	+	+	−		−	−		

| Cultural features | | | | | | | | | | | | | | | | Biochemical features | | | | | | | | | | | | | | | |

Brandt denies Hertwig's idea that the oil droplet represents a storage of general food supply. He cites its enormous size and definite position as proof that it has some very special function. Also he quotes the work of Panceri and Radziszewisky to show that all luminous animals use a fat-like substance with which to produce light. Better than all, however, is his observation under the microscope that it is the extreme centre of each individual in a colony that lights. He states that this central point of light was rather large to be the oil droplet alone.

The facts of the case appear to the writer to be as follows: Recent studies have shown that luciferine is not a fat-like body soluble in alcohol, as this oil droplet appears to be. But, as described

FIG. 4.

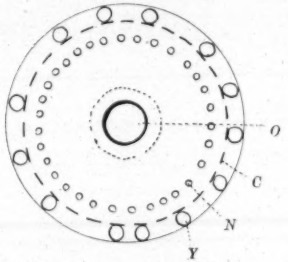


Diagram of a "nest" or individual colony of *Collozoum fulvorum*. *C*, central capsule; *O*, oil droplet; *N*, nuclei of the colony; *Y*, yellow cells (symbiotic algæ). (Modified after Brandt.)

by Brandt himself, this body in the centre of the Radiolarian individual is not a homogeneous fat. It has an outer zone (Fig. 5) from which the fat can be squeezed, and this outer zone is not soluble in alcohol.

It is in this zone or in the shell of cytoplasm next to it that the light originates. Also it is probable that the materials for the secretion of luciferine are stored in the fat droplet and are withdrawn and elaborated by the nearby cytoplasm in which they rest until a stimulation causes them to be consumed in order to produce the light.

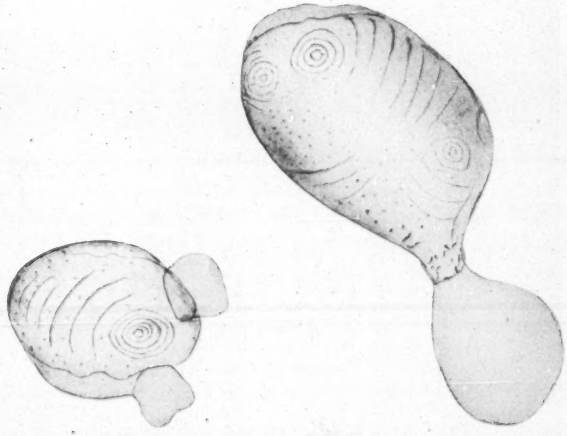
As to the use of the light or its biological meaning we have no clue. It possibly may serve as a warning signal. But it cannot be used to serve as an attraction or as a light by which the crea-

tures can secure their prey, for the Radiolarians are quite motionless and cannot see. Also the light is a rather weak one.

Another group of protozoa, the *Peridiniaceæ*, as they are called by the botanists, or the *Dinoflagellata*, as the zoologists have named them, are also luminous.

These organisms are found all through the superficial seas of the world, and also in fewer numbers in fresh water. They are unicellular and are covered by a stout coat of cellulose, which

FIG. 5.



Two oil droplets from the centres of two individual colonies of *Sphærozoum neapolitanum*. These have been pressed under the cover-glass and show the oil-like material being pressed out in masses from the thick, soft covering. (After Brandt.)

is composed of two pieces, with more numerous plates, and is of various beautiful forms, according to the species. There is a constant groove present in all the forms, in which lie two stout, fleshy cilia or flagellæ that the animal uses to propel itself with. Chlorophyll and some red and brown pigments are present in some of the forms, although the pelagic forms are usually transparent. As typical of the group we will study the production of light in three forms, *Ceratium tripos*, *Peridinium bahamense*, and in an unidentified colonial form found in the lower parts

of Delaware Bay and Chesapeake Bay, as well as other bays and sounds on the Atlantic coast of North America from New York to Florida.

Ceratium tripos was probably the first of these forms to be studied. It was thought that it produced light as distinct from *Noctiluca miliaris* as early as, or perhaps earlier than, 1811, when Tiedemann investigated it among the other marine "infusorians"

FIG. 6.

Photograph of living *Ceratium tripos* under a medium magnification. Dark stage illumination. × 125 diameters. (Original.)

that shone. Many other investigators and travellers mentioned light that probably came from some of the Dinoflagellates, but Ehrenberg was the first, in 1831, to look into the question in any adequate way. Later, some of the best work has appeared in monographs and papers by G. Schütt, Reinke, Gourret, Molisch, Zacharias, and others.

Ceratium (Fig. 6) is found over most seas at the surface. While usually present or abundant, it is sometimes enormously

frequent. The writer once saw it off the coast of Nova Scotia, about ten miles off shore from the entrance to Liverpool Bay, so thick on the surface that it made the water as smooth as glass and prevented a fair, full-sail breeze from rippling the water. As the breeze rose with the advancing day it was able to mark the water with occasional cat's-paws, and finally became strong enough to throw it into ripples. A tow net of finest bolting cloth, when dragged a few yards through this water, became filled with several pints of a clear, somewhat mushy jelly which was composed almost exclusively of *Ceratium*. Unfortunately no observations were made on the luminosity during the succeeding night.

Many of the investigators mentioned above have determined the fact that *Ceratium tripos* actually does produce light. Molisch picked out several individuals and placed them living in sea-water on a slide under the low power of the microscope, and by stimulating them by various chemical means, as alcohol, distilled water, acids, etc., caused them to show their light.

Zacharias, while studying them in Kiel harbor in Germany, noted that they never lighted spontaneously, but only when they hit one another or collided with some other object. Thus they appear to shine only when disturbed by some chemical, mechanical, or other stimulus. The writer and Mr. Carl Speidel spent some time in careful observations on this form at Harpswell, Maine, in 1915. They were fairly abundant on the surface at night in the surrounding sea, and extended to the beach. Their light was very easy to compare with the light of the numerous young Ctenophores in the water. While the Ctenophore light was brilliant green, that of the strongly-stimulated *Ceratium* was silvery white. The creatures were shining all around the resting rowboat in occasional sparks, probably caused by their mutual collisions. When a medium coarse bolting-cloth net was drawn through the water a shower of silver sparks formed a brilliant spray in its wake, while the larger Ctenophores showed their bright green light as they stuck in the meshes.

Ceratium was evidently first stimulated as it was roughly drawn by the current through the meshes of the net, the stimulus consisting of its contact with the hard silk threads. It did not light until it was about 10 mm. past the net. Then came the flash, which lasted for from eighteen inches to two feet from the net. Thus the flash was not of one second's duration, although

BACILLUS PFLÜGERI GROUP.

B. PLYMOUTHII = B. PFLÜGERI, LUDWIG = B. FISCHERI, MIG. = B. FISCHERI, MIG. = BACILLUS PFLÜGERI, LUDWIG

Name	Synonyms	By whom found	Where	When	Authorities
Micrococcus phosphorescens, Cohn	M. Pflügeri, Ludwig ex parte M. Lucens, v. Pieghem Photob. phosphorescens, Bey. Bact. Lucens, Nuesch Arthra bact. Pflügeri, De Bary	Pflüger Cohn Ludwig Beyerinck Nuesch	Fish Meat	1874	Pflüger, '74. Cohn, '78. Nuesch, '77, '80. Schroter, '86. Ludwig, '87. Migula, 00, p. 78, Fig. Bd. I. T. a.y.
Bacillus Fischeri (Beyerinck), Mig.	B. phosphorescens indigenus, Kruse B. argenteo-phosphorescens (Katz), Mig. B. argenteo-phosphorescens I, Katz Einheimischer Leucht bacillus, Fischer Photob. Fischer, Bey. Microspira Fischeri (Bey.), Chester Vibrio Fischeri (Bey.), L and N.	Fischer Katz	Kiel Harbor Elizabeth Bay, N. S. Wales Baltic Sea	1888 1887	Fischer, '88. Beyerinck, '90. Katz, '91. Flugge, '96, p. 331. Migula, '00, p. 866, 869. Lehm. and Neum., '01, p. 371. Matzuschita, '02, p. 76, 298. Miquel and Cambier, '02, p. 881, 885
Bacillus Balticus (Fisch.), Bey.	B. phosphorescens Balticus, Matz. Photob. balticum (Fisch.), Bey. Vibrio balticus (Bey.), L. and N.	Fischer Beyerinck	Baltic Sea		Fischer. Lehm. and Nuem., '01, p. 371. Matzuschita, '02, p. 78. Barnard, '99, Figured.
Bacillus phosphorescens, Fischer	B. phosphorescens indicus, Kruse B. cyaneophosphorescens, Katz B. phosphorescens, Matz. Photob. indicum (Fisch.), Bey. Photob. cyaneum, Ludwig. Vibrio indicus (Bey.), L. and N.	Fischer Katz Beyerinck	Caribbean Sea Australian Ocean	1887 1887	Fischer, '89. Beyerinck, '90. Katz, '90. Flugge, '96, p. 330. Mace, '97, p. 933. Migula, '00, p 866. Lehm. and Nuem., '01, p. 370 Matzuschita, '02, p. 76, 68. Miquel and Cambier, '02, p. 882. Barnard, '99, Figure.
Bacillus phosphoricus, Mig.	B. argenteo-phosphorescens III, Katz.	Katz	Australian O. and Squid., Sydney	1887	Katz, '91. Migula, '00, p. 870. Matzuschita, '02, p. 98. Miquel and Cambier, '02, p. 882, 884.
Bacterium argenteo-phosphorescens (Katz), Mig.	B. argenteo-phosphorescens II, Katz B. argenteo-phosphorescens immobilis, Matz.	Katz	Australian Ocean Squid and fish, Sydney	1887	Katz, '91. Migula, '00. Matzuschita, '02, p. 374. Miquel and Cambier, '02, p. 882.
Bacterium Giardi (Kruse), Mig.	B. phosphorescens Giardi, Kruse Photob. Giardi, Giard u. Billet. Photob. pathogenicum, Giard	Giard	Crustacea	1889	Giard, '89. Flugge, '96, p. 333. Matzuschita, '02, p. 374. Miquel and Cambier, '02, p. 883.
Bacterium liquefaciens plymouthii, Barnard	Photob. liquefaciens plymouthii, Barnard	Barnard	Polyzoa, Plymouth	1899	Barnard, '99, Figure.
Bacterium Pflügeri (Ludwig), Chester	Photobacterium Pflügeri, Ludwig B. phosphorescens gelidus, Förster B. phosphorescens Pflügeri, Kruse	Förster Pflüger	Fish Fish, North Sea	1874	Ludwig, '87. Förster, '87. Flugge, '96.

(Ludwig), Chester	B. phosphorescens Pflugeri, Kruse Bact. Lucens, Nüesch M. Pflugeri, Ludwig ex parte	Ludwig	Meat	1874	Flugge, '96. Matzuschita, '02, p. 374. Miquel and Cambier, '02, p. 885.
Bacterium phosphorescens, Fischer	B. smaragdino-phosphorescens, Katz Photob. phosphorescens, Bey. Photob. phosphorescens gelidus Bact. smaragdino-phosphorescens (Katz), Mig. Bact. smaragdinum (Katz), Chester Microspira phosphorescens (Fischer), Chester	Fischer Katz	North Sea Herring, Sydney	1887	Fischer, '87. Beyerinck, '90. Lehmann, '89. Tollhausen, '89. Katz, '91. Barnard, '99, Fig. Migula, '00, p. 433. Matzuschita, '02, p. 374. Miquel and Cambier, '02, p. 885.
Microspira annularis (Fischer), Mig.	Photob. annulare, Fischer Microspira annulare, Fischer, Mig.	Fischer	English Channel	1889	Fischer, '94. Migula, '00, p. 1014.
Microspira coronata (Fischer), Mig.	Photob. coronatum, Fischer B. phosphorescens coronatus, Matz. Microspira coronata (Fischer), Mig.	Fischer	English Channel	1889	Fischer, '94. Migula, '00, p. 1014. Matzuschita, '02, p. 76.
Microspira degenerans (Fischer), Mig.	Photob. degenerans, Fischer Microspira degenerans, Fischer, Mig.	Fischer	North Sea	1889	Fischer, '94. Migula, '00, p. 1015.
Bacillus tuberosus, Fischer	Photob. tuberosum, Fischer Microspira tuberosa (Fischer), Mig.	Fischer	North Sea	1889	Fischer, '94. Migula, '00, p. 1014.
Bacillus hirsutus, Fischer	Photob. hirsutum, Fischer	Fischer	North Sea, fish	1889	Fischer, '94.
Pseudomonas javanica (Eij.), Mig.	Photob. javanense, Eijkmann B. javanensis, Matz.	Eijkmann	Fish, Java	1891	Eijkmann, '92. Migula, '00, p. 953. Matzuschita, '02, p. 338.
Microspira caraibica (Fischer), Mig.	Photob. caraibicum, Fischer B. phosphorescens, caraibicus, Matz.	Fischer	Caribbean Sea	1889	Fischer, '94. Migula, '00, p. 1015. Matzuschita, '02, p. 340.
Microspira Dunbar, Mig.	Photospirillum, Dunbari Vibrio, Dunbari Vibrio phosphorescens, Dunbari-Rumpel Vibrio albensis, L. and N. Phosphorescent elbe vibrio, Kutscher and Dunbari	Dunbar	River Elbe, Hamburg	1889	Dunbar, '93. Kutscher, '95. Migula, '00, p. 1013, Fig. Lehm. and Neum., '01, p. 370, Fig. Matzuschita, '02, p. 108.
Microspira luminosa (Bey.), Mig.	B. luminosa, Kruse B. phosphorens (Katz), Mig. B. argenteo-phosphorescens liquefaciens, Katz Photob. luminosum, Bey. Vibrio luminosus (Bey.), L. and N.	Beyerinck Katz	North Sea Fish, Delft	1888 1887	Beyerinck, '89. Katz, '91. Flugge, '96, p. 331. Migula, '00, p. 1015. Lehm. and Neum., '01, p. 371. Matzuschita, '02, p. 76. Miquel and Cambier, '02, p. 884.
Microspira glutinosa (Fischer), Mig.	Photob. glutinosum, Fischer	Fischer	North Sea English Channel	1889	Fischer, '94. Migula, '00, p. 1014.
	IMPERFECTLY DESCRIBED.				
Bacterium pholas, Dubois		Dubois	Pholas		
Bacterium pelagia Dubois		Dubois			
Bacterium saycophilum		Dubois	Lyon, France, meat	1891	Dubois, '98, Fig.
Microspira delgadensis (Fischer), Mig.	Photob. delgadense, Fischer	Fischer	Water and fish, Ponta Delgada	1889	Fischer, '94. Migula, '00, p. 1014.
Microspira papillaris (Fischer), Mig.	Photob. papillare, Fischer	Fischer	North Sea	1889	Fischer, '94. Migula, '00, p. 1016.

probably nearly as long as that short time. An after-glow of a faint greenish light persisted after the flash as the organisms were swept further behind the net by its motion through the water. It is thought that the first flash seemed white or silvery mostly because of its brightness or strength, but partly because of a different quality of its light waves.

A second method of lighting was also observed. When the plankton was towed at night and brought into the laboratory in a bucket of sea-water the *Ceratium* were lifted out of water on the hand or on a bit of clean cloth or paper. When thus caught and held captive they glowed for several seconds to several minutes with a weaker greenish light that still was not as green as that of the *Ctenophores*. This was probably their death-glow or glow of exhaustion.

Zacharias made an interesting observation on the periodicity of the light power. He found that from early daylight until 5 o'clock in the afternoon *Ceratium* was entirely unable to light. Only after 5 P.M. (by which time it was dark at that season of the year in Kiel) did the light power develop. The writer and Mr. Speidel have observed the same fact at Harpswell, Maine, when the *Ceratium* did not begin to light in early dusk, but only after real summer darkness had set in. We know that the bacteria shine continuously night or day, in light or darkness.

Many species of *Peridiniaceæ* live in fresh water, and some of them are much of the same form and structure as salt-water forms. These fresh-water forms have been carefully investigated, and it has apparently been proved that none of them has the power of light production. The form *Peridinium bahamense* was first described in 1906 by L. Plate from the "fire-lake" on the island of New Providence, in the Bahama Archipelago. In this little lake of salt water with an inlet to the sea is nightly to be seen a beautiful exhibition of light. The source of the light is, without doubt, the great mass of unicellular Dinoflagellates, *Peridinium bahamense*, which Plate found here (Fig. 7).

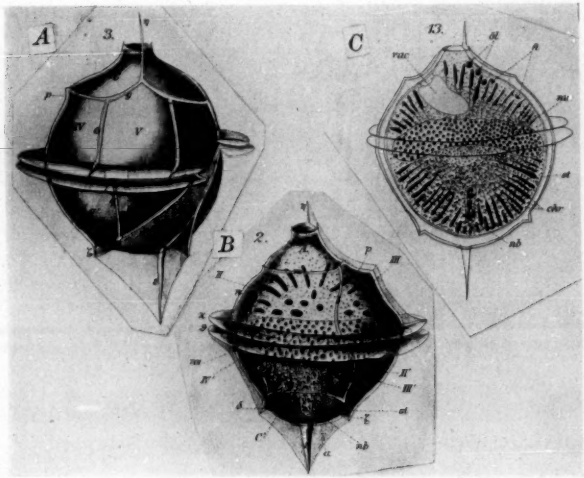
Plate shows that these organisms respond to all chemical and mechanical or physical stimuli with a flash of light. He feels, although he has not proved it, that the flash of light may sometimes be spontaneous.

It is of interest to note at this point that Plate describes the

light of this form as "silver-white," thus making it agree with the light of *Ceratium tripos* as observed by the writer and Mr. Speidel. Perhaps the most interesting part of Plate's work is a careful description of the cytoplasm and nucleus of *Peridinium*, with some remarks on the probable seat of luminosity.

The organism has a compact, round, protoplasmic body containing a large nucleus whose shape can best be described as like

FIG. 7.



Drawings of *Peridinium bahamense*. A. View of the outside as an opaque object. B. View of organism as a transparent object. C. View of a median vertical section. *nu*, Nucleus; *nb*, nebenkoerper; *chr.*, chromatophores; *fl.* fat drops; *ol.* upper oil drops; *ub*, lower oil drops. (After Ludwig Plate.)

that of a very short, thick sausage bent sharply into a semicircle and placed with the plane of the curve almost coinciding with the equatorial plane of the organism. The flagellum groove lies in this plane.

Radiating out in the cytoplasm from an approximate centre are a series of elongate bodies, the chromatophores, which bear a brown pigment. These bodies probably have nothing to do with the production of light. Besides these, however, are a series of

other inclusions, the *nebenkoerper,* the anterior oil drops, the fat bodies, and the posterior fat drops, as well as one large, fluid-filled vacuole. We can dismiss the vacuole as a probable excretory organ, and as such not a directly active body in the production of light.

The *nebenkoerper,* however, from its position and unusual structure, might be the origin of the luminosity. Plate thought that he could see that the light came from the posterior part of the body. Until we know more of the microchemistry of lucifer-

FIG. 8.

Photograph of a drawing of a colonial peridinium from the waters of lower Chesapeake Bay, as they appeared when luminous under a low magnification. (Drawn by E. Grace White.)

ine, or until we can actually see the light emanating from the *nebenkoerper* or its surrounding fat droplets, it will not be possible to say which of these bodies are the ones that shine.

The last example of this large group that should be discussed here is the colonial form of the group *Peridiniaceæ,* seen by the writer in the waters of Delaware and Chesapeake Bays. This organism is figured as living and shining in Fig. 8. In life it is of a reddish-brown color and very small. The long, eel-shaped colonies, sometimes consisting of hundreds of individuals, swim in stately curved paths through the water, each individual always passing through the same spot that the leader did, no matter how

many curves have been described by the colony. The larger colonies are easily separated into smaller units.

In the daytime the creatures form large patches of reddish water, from a few feet across to several acres. The fishermen at Norfolk told the writer that this reddish water was fresh water from the Dismal Swamp, tinged red with the tannin and coloring matter from the cypress and oak leaves, and that this water was boiling up from underground streams that opened into the bottom of the bay. A glassful of the reddish water and a Coddington lens soon showed that the color was due to the organism under consideration, and not to the Dismal Swamp.

It was remarkable how the creatures remained in each other's company and did not get generally distributed through the water by the swift currents and waves of the region.

While a passenger on a steamer that traversed these same waters in the night the writer saw one of the most beautiful exhibitions of luminosity imaginable. The boat would enter (by inference) one of the patches of red water and her bow and stern waves, as well as the friction water along the sides and the wake, were a mass of bright green fire. Also the roughening sea showed every tiny wavelet with its crest and back slope alight. The light was so bright that passengers in their state-rooms, with windows opening on the sides, saw the light reflected on the ceiling of the state-room and asked afterward what light we had passed or what steamer with her lights lit. The noticeable thing about this light was its vivid green quality, as well as the fact that it lasted longer than the silvery light of *Ceratium tripos*.

A polar view of a single member of the colony (Fig. 9) shows a large number of vacuoles containing some substance which is not a real fat (does not blacken with osmic acid) and which the writer believes to be luciferine.

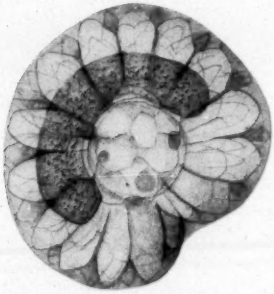
The *Cystoflagellata* are perhaps our best and most classic example of one-celled, light-bearing organisms. They shine the brightest, are perhaps largest, and have been known longest. Also more eminent scientists have studied them and published careful work concerning the light-producing power.

The animals are large for unicellular forms, and the entire group consists of only a few genera, all of which are luminous. These kinds are *Noctiluca*, *Pyrocystis*, *Leptodiscus*, and *Craspedotella*.

Of these few forms we will consider only the first, *Noctiluca miliaris*, Suriray, which was known to be a luminous creature of the ocean's surface as long ago as 1717 by Dartons de Mairan. Many have studied this form since, and the more casual studies, reports, and observations are so numerous that we will note only the more recent and important ones here.

Ehrenberg isolated this organism from other forms on the surface of the North Sea in 1834, and observed them sparkling and shining in a watch-glass full of sea-water. By using brandy, spring water, heated sea-water, or shaking as a stimulus, he saw the creatures respond with their flash and glow of light.

FIG. 9.



Polar end view of a single member of a colonial peridinium from Chesapeake Bay. Transparent view of Flemming fixation. The curved, sausage-shaped nucleus partly surrounds a central clear area, while the large vacuoles radiate out from this area. × 175. (Drawing by E. Grace White.)

It was Quatrefages who in 1850 studied *Noctiluca* most carefully and discovered some very important facts about their luminosity.

One of the most interesting pieces of work done on *Noctiluca* was his study of the creature under the microscope. When seen under a low magnification, even, it was perceived that the whole body did not shine, although the illuminated part appeared of a solid brilliancy. The light seemed superficial and was confined under ordinary stimulus to a spot covering about one-sixth of the entire surface. When magnified thirty times this spot could be well seen, and it was noticed that two such spots were on the surface and that they moved (Fig. 10) around on opposite sides.

When greatly disturbed these spots were extended until the whole surface was aglow, but this could continue for only a short time.

Quatrefages then magnified the animal with a higher-powered lens to 60 times, and saw the lighted "blush" of the *Noctiluca* as a milk-white ground with a number of shining points on it. Again he increased the magnification to 150 times, and then saw clearly that the entire luminosity was due to a vast number of tiny points from which the light streamed (Fig. 11).

These points were constant in position and were lighting up one after another on the side of the blush which was advancing,

FIG. 10.

Photograph of a drawing representing *Noctiluca miliaris* as it appears when lighting. (Original.) × 30.

and also they were going out on the side that was receding. Thus the luminous area advanced in a steady progress, although the actual spots that composed it were fixed organs in which the luciferine was secreted and used. In this way the organism is able to remain illuminated for a considerable time.

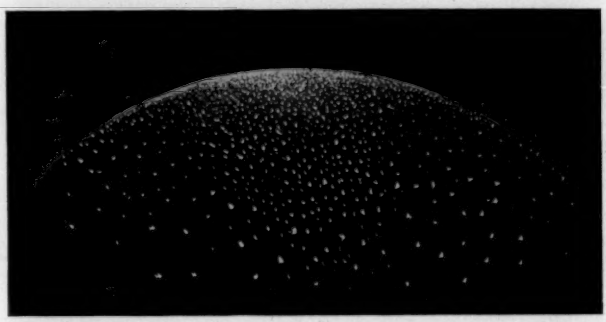
Noctiluca is extremely abundant in most seas at certain times and, owing to its red pigment, it may color the water various shades of red, sometimes blood-red. In the surface water of the North Sea they are sometimes so abundant that a glassful of water will show one-seventh of its bulk to be *Noctilucas*.

Quatrefages describes very beautifully the appearance at

night of certain small bodies of water on the coast of France in which *Noctiluca* is the principal source of light. He describes the still black waters, and how a grain of sand thrown in will produce a small spot of light, how a stone will send out ripples of light, and how the constant friction of the small wavelets or swell on the sandy shores is the cause of a border of sparkling light to the dark pool. He mentions this light as silvery-white. We thus see that it apparently corresponds to a degree with the color of the light of the Dinoflagellates.

One of the first experiments tried by Quatrefages was to see if the luminous material secreted by the animal was discharged

FIG. 11.



View of *Noctiluca miliaris* under a magnification of 200 diameters to show that its light originates as a series of light points that make up the superficial wave of light or "blush" that travels over its body. (After Quatrefages.)

from the body. To do this he filtered a large basin of water containing thousands of the creatures through a sieve that was just fine enough to hold the animals back. The water that ran through the sieve showed no light, which was accepted as proof that the luciferine was kept inside the body during combustion. His observations on the source of the light as described on a previous page also confirm this.

He also found that small portions of the animal's flesh cut apart from the body continued to light as though nothing had happened. A more important experiment was to fill a tall glass vessel with water that was laden with *Noctiluca*. These organisms rose to the surface as a thick layer, and the under ones

continued to light as brilliantly as those on the surface when stimulated. Quatrefages believed that the numerous lower layers had used up the air in the surrounding water and were lighting in the absence of air. The writer does not agree with this, and would insist that the experiment be tried under more exact conditions before such a result is accepted.

The experiments to determine the intensity of the light were interesting, although lacking such accuracy, for instance, as Lode's more recent experiments with bacteria that were described in a previous chapter. Quatrefages filled a tube 15 mm. in diameter to a depth of 10 mm. with the living organisms and then compared their light under strong stimulation with that of a common household candle. He states that the lights were about equal. This at least shows great brilliancy for *Noctiluca*, since the surface dimensions of an ordinary candle flame and that of this mass of Noctilucas must have been in some degree comparable, if not equal.

Another point of great interest was the interesting observations made by this gifted scientist on the two different methods of lighting shown by *Noctiluca*. The first has been described already in a preceding paragraph of this article as the lighting up of a part, or possibly of the entire surface, of *Noctiluca* by the sharp flashing and shining of distinct points that worked in unison. The second only appears as an antemortem condition, and consists of the pale, continuous shining of all possible points of the animal's surface. This condition may last for several minutes or until death has set in. The writer has observed and mentioned on a preceding page a somewhat similar condition in *Ceratium tripos*.

Quatrefages also noted that whatever stimulus caused light also caused motion. The writer can see that this is probably true, but does not believe that the two processes are inseparable. We know that motion does take place without light, and I am quite sure that the light may take place without motion.

Besides these three forms of protozoa which produce so beautiful a light, no other one-celled organisms besides the bacteria can do the same. At least a careful search has shown plenty of other protozoön forms in the sea, but no light bearers among them. Perhaps others may be found by future investigators.

(*To be continued.*)

Poisons Used in the Rubber Industry. ANON. (*United States Commerce Reports*, No. 262, November 8, 1915.)—Rubber manufacture involves the use of numerous poisonous substances, of which lead salts, antimony pentasulphide, aniline oil, carbon disulphide, and carbon tetrachloride are the most dangerous. The operations involving exposure to these poisons, however, employ but a small proportion of the large number of workers. No women and very few boys are engaged in such operations. A lesser danger is found in the use of coal-tar benzol and of various petroleum products, such as naphtha, benzine, etc. A considerable number of the workers, including women and boys, are exposed to the fumes of these compounds. These facts are brought out in an investigation by Dr. Alice Hamilton of the industrial poisons used in the rubber industry, the results of which have just been published as Bulletin 179 of the Bureau of Labor Statistics of the Department of Labor.

While it was impossible to get complete data as to the frequency of industrial poisoning in the rubber industry, records were secured of no less than 66 cases of lead poisoning which occurred in 1914 among the rubber workers in the United States. Cases were also found of naphtha poisoning, and of poisoning from carbon disulphide, carbon tetrachloride, and aniline oil.

The dangerous nature of some of the compounds used in the rubber industry is not yet commonly known, so that cases of industrial poisoning may occur without being recognized as such and ascribed to their true cause. Also, in the case of some of the compounds, the symptoms of poisoning may be obscure or may not develop until some time after the exposure has taken place, so that again the resulting harm may not be ascribed to its true cause.

The investigation on which the bureau's report is based covered 35 rubber factories, located in 15 cities or towns in 9 States. Practically every branch of the rubber industry was included among the activities of these factories. As there are many trade secrets in the manufacture of rubber articles, it was impossible to make the investigation as complete as was desired.

It is possible to equip and manage a rubber factory so that exposure to the various industrial poisons will be reduced to an insignificant minimum or wholly eliminated. Relatively little, however, seems to have been done in this direction.

NOTES FROM THE U. S. BUREAU OF STANDARDS.*

MEASUREMENTS FOR THE HOUSEHOLD.[1]

THE purpose of Circular No. 55, just issued by the Bureau of Standards, is (1) to give information as to units, methods, and instruments of measurement useful in household activities, (2) to describe available means of assuring correct quantity in articles bought by weight and measure, and (3) to give other facts of interest which would awaken an appreciation of the rôle of measurement in daily life.

In the scientific investigations of numerous questions the Bureau of Standards has accumulated general information which may be known to the industries concerned, and hence of less novelty to them, but is often of great value and importance to the general public. For example, watchmakers are familiar with the construction and adjustment of watches and clocks, and the best methods of caring for them, but the ordinary purchaser who uses them is often at a loss to obtain the most elementary knowledge of how to properly care for them. In the same way, to electrical and gas engineers information given in this circular is everyday knowledge, but the householder, while deeply concerned about the indications of his meters and the quality of the gas supplied to him, often finds it difficult, if not impossible, to secure simple technical information that is often of great value to him. It was with the purpose of making the results of the work of the Bureau available to the public in so far as this work is related to the work of the household that this circular has been prepared.

RÔLE OF MEASUREMENT IN DAILY LIFE.

Household measurements suggest many interesting phases of the art of measurement. The significance of measurements in our civilization and their effect upon everyday life may not be fully appreciated. From the beginning of life measurement is important. The infant should weigh about so much, and the number of pounds is one measure of its condition. Its weight should increase at a normal rate, and here the weight becomes an

* Communicated by the Director.

[1] Circular 55, Bureau of Standards, Washington, D. C.

index of nutrition and good health. The measure of body temperature is an advance indicator of illness. Especially in recent scientific studies of childhood is the importance of measurement keenly realized. The repsonse of muscles and nerves—the measure of the so-called time reactions and sense perception—are elements in studying educational methods, especially subnormal cases. It is possible to set certain approximate standards for the normal child and its growth. Measurements are made of the speed, strength, and fatigue of its reactions; of its height, girth, and other dimensions. Muscle measures and strength tests indicate normal growth or the effectiveness of physical training. The ergograph measures endurance, and the chronograph records perceptions and reaction times. The focusing power of the eyes is measured, and with these measurements the optician can perfect the vision by adapting the measured curvature of glass to the measured defect of vision. The correct measures of the body determine the comfort and effectiveness of clothing.

Modern industry owes its efficiency largely to careful measurements which control processes, or fix the dimensions, proportions, and properties of products. Accurate parts of machines or accessories make it possible to manufacture the parts separately and assemble them without special hand fitting. Any one may then order repair parts, knowing that they will fit into the machine. In many industries the measured control of heat, electric current, or power is essential to efficient operation. Bread should rise at a definite temperature, steel should be quenched at a certain stage in cooling to give the best results, and similar account must be taken of many things to secure the desired quality.

Properties of materials are measured or tested, and this gives a means of controlling quality. Measurement guides the processes of all industries and keeps their output up to certain standards. Careful determinations of the properties of materials are coming to mean more and more to business and industry, and the determination of properties of standard materials is an ever-increasing part of the work of this Bureau.

MEASURES OF TRADE AND THEIR INSPECTION.

The Bureau of Standards is also active in the phase of measurements that touches the household very directly—the weighing and measuring of goods bought, sold, and transported. Much in-

accuracy and fraud exist. Weights and standards and instruments are subject to accident, deterioration, and tampering. For these reasons systematic inspection of trade weights and measures is regarded as a function of the government. In order that the standards throughout a country should be uniform, the custody of the fundamental standards rests with the National Government, which is authorized to fix the standards of weight and measure. In the United States the actual inspection service, being necessarily local, has been left to the States and cities. This Bureau's work has been (1) to provide the States with standardized sets of weights and measures, (2) to encourage and stimulate intelligent interest in the State and local regulation and inspection of weights and measures, (3) to coöperate with the local sealers regarding the technical details of inspection service, and (4) to gather data regarding the standards and instruments in use.

MEASUREMENTS OF HOUSEHOLD PRODUCTS AND PROCESSES.

Improved precision has slowly evolved from the guesswork of earlier times. For example, terms like the "pinch of salt," "speck of pepper," "handful of rice," "sweeten to taste" (units of vague magnitude) have gradually been replaced by definite amounts specified and measured. A process is uncertain of success unless the effect of all the factors entering into it is known. In factories where food is prepared on a large scale, temperatures are carefully measured or determined automatically, and amounts and times are accurately controlled. These methods, which make for efficiency and economy, are being used more and more in the household.

Such measurements as require costly or delicate apparatus can not yet be expected to be common in the home; and some still think that the measurement of temperature of rooms, of ovens and syrups, and the weighing of purchases, etc., are unimportant. However, scales, thermometers, and a few other simple measuring appliances can be obtained for a small expenditure, and this circular will attempt to show some of the advantages of their use. Measuring instruments for household use which are automatic, or which may easily be operated without special training, are becoming more and more available.

HOUSEHOLD MEASURING APPLIANCES.

A large variety of measuring appliances are used in connection with the household work. A description of the kinds of appliances will be found in more or less detail in the several sections of this circular; they include the following groups:

1. A test set of weights and measures for checking purchases and other purposes.
2. Meters for measuring the delivery for household use of gas, water, and electricity.
3. Special measuring instruments, such as thermometers, hygrometers, barometers, hydrometers, and timepieces, for measuring temperature, moisture, pressure, density, and time.
4. Special measures used in cooking.

The efficient management of the modern household is greatly promoted by the careful use of well-selected measuring appliances, and one of the purposes of this circular is to guide the housewife in the selection and use of such appliances.

EDUCATIONAL VALUE OF HOUSEHOLD MEASUREMENTS.

Apart from the direct use of the results of measurements in the household, they are, when properly made, of educational value. Hazy ideas of process and dimension become clear and definiteness of thought is gained. Opportunities for measurement are a means of education for children which should not be ignored. The habit of thinking in terms of units and definite quantities can not fail to increase the efficiency of the individual and the household. The practical measurement of purchases may be made a means of education in appreciating and estimating quantities. Boys may easily construct rough measuring instruments and devise methods of measurement of such things as air-pressure, wind velocity, temperature, etc. The measurement of areas and volumes of rooms; the heights and weights of individuals; of the growth of children, etc., are all matters which lend themselves to educational uses. Some of the information given in the chapters of this circular, for example, on light, on gas meters, on the use of clocks, on humidity, etc., may lead to observations and experiments of considerable educational value. In general, it may be said that the educational and other uses of household measurements are almost unlimited and but little realized.

UNITS AND TABLES.

In the appendix will be found tables of units and special data regarding measurements. Many of the units used are somewhat vague and in some cases the terms are ambiguous. For example, the *ounce* used in the drug store is not the same as the ounce used in the grocery store, even when the same commodity is purchased, and the *fluidounce* is different from either, and is not a weight at all. It will thus be seen that for more careful work in connection with measurements the exact value of the units used should be clearly known. The growing use of the metric system throughout the world is rapidly introducing simplicity and definiteness in place of existing confusion, since in that system there is but one name for each unit and the unit has but one value throughout the world. Since the American Pharmacopœia now uses the metric system as the only system of measurement in the formulas for drugs and medicines, a knowledge of the metric system is increasingly desirable, especially in connection with the prescription and use of medicine and other compounds. In domestic science and related sciences the knowledge of the metric system is indispensable to the best work, since everywhere the more technical aspects of these subjects usually involve the use of the metric system. A pamphlet descriptive of the metric system may be obtained upon application to this Bureau.

Measuring the Discharge through a Venturi Tube with a Direct Reading Meter. J. Dejust. (*Comptes Rendus*, vol. 161, No. 16, October 18, 1915.)—The method here proposed for measuring the discharge consists in replacing the usual apparatus for measuring the pressure difference between the full and the contracted sections of the tube and the integrating mechanism with an ordinary meter. The difference in pressure between the large and small sections of the tube causes a discharge between these two points.

The intake of the meter is directly connected to the full up-stream section of the tube; between the outlet and the down-stream contracted section of the tube a diaphragm is introduced. The algebraic expression of the ratio of the discharge through the tube to that through the by-pass containing the meter shows that this ratio is not constant. By adjusting the section of the by-pass tube and its diaphragm, however, the terms which are not constant can be reduced to a negligible value and the ratio made substantially constant for various rates of discharge. The constancy of this ratio has been tested on a line 100 mm. in diameter, provided with a Venturi tube

having a contraction of 16 to 1, with a by-pass 20 mm. in diameter, a meter orifice of 12 mm., and a diaphragm calculated to make the ratio of meter discharge to flow through the line, 1 to 100. By varying the velocity in the line from 0.16 meter to 1.23 meters, the ratio varied from 103.82 to 105.53; that is to say, 1.65 per cent. of the smaller number. Reckoning from the mean of these two values, 104.675, the maximum error will be 0.82 per cent. of the true discharge.

Water Powers of the Cascades. ANON. (*United States Geological Survey Water-Supply Papers Nos. 253 and 313.*)—Well to the west of the great rock barrier which in the early days of the Republic was assumed to be the natural western boundary of the United States lies another great belt of elevated land surmounted by a chaos of rugged peaks and pyramids—the Cascade Range of Washington and Oregon. In these mountains there is an inexhaustible store of potential wealth, much of it belonging to the nation—not precious or useful metals, for mines, however rich, must eventually become exhausted, but a wealth of running water, an endless chain revolving with the seasons. The streams of the Cascades possess in high degree the requisite characteristics for the successful development of water power; namely, steep gradient, abundant water, and comparatively uniform flow. Add to these the enormous resources of timber, metallic and other minerals, and lands as yet developed only in small part but promising an extensive future market for water power, and it becomes apparent that the large areas of country surrounding the Cascade Plateau have in the undeveloped power of their streams very great potential wealth.

The United States Geological Survey, in coöperation with the Washington State Board of Geological Survey, has made a comprehensive survey of the water resources of this area in that State. Water-Supply Paper 313, issued by the Federal Survey, entitled "Water Powers of the Cascade Range, Part II," is the second of a series of reports resulting from this work, the first having been issued as Water-Supply Paper 253. This second report deals principally with the drainage basins of Cowlitz, Nasqually, Puyallup, White, Green, and Cedar Rivers. It includes all monthly estimates of river discharge derived from data collected by the water-resources branch of the Geological Survey in coöperation with the State Board of Geological Survey and by private persons.

The summaries of the available power in each basin are computed from the average flow for the lowest week on record and from the flow that could be realized from possible storage. The flow with storage is computed on the basis of the continuous discharge that can be maintained by the release of the stored water during the most extreme drought on record, considering the length and severity of low-water periods.

NOTES FROM NELA RESEARCH LABORATORY.*

VISUAL PATTERN-DISCRIMINATION IN THE VERTEBRATES. IV.—EFFECTIVE DIFFERENCES IN DIRECTION OF VISIBLE STRIÆ FOR THE MONKEY AND THE DOMESTIC CHICK.[1]

By H. M. Johnson.

THE following experiments were made by the Yerkes-Watson discrimination-method on one Capuchin monkey and two Indian gamecocks. The discriminants were two circular fields 6 cm. in diameter, 6.2 candles per square metre in mean brightness, the spectral distribution approximating that of a tungsten lamp operated at a specific consumption of 1.25 watts per candle. Both fields were covered with alternate dark and bright striæ equal in width and separation, and distinguishable by the animals as such under the experimental conditions. The striæ on the positive field were horizontal; those on the negative field deviated from the horizontal direction by a definite and variable amount. In the beginning of the training the difference was 90 degrees, and was decreased by small gradations after the animal had formed a perfect discrimination-habit.

One chick failed to learn the problem in 800 trials. A second chick established a perfect habit in 585 trials distributed over 58 days. There was consistent improvement after 280 trials. The monkey learned the problem in the first daily series of 20 trials, during which he made but two errors.

The difference in direction effective in half the total number of trials, as shown by an average percentage of correct choices of 75, is between 2 degrees and 5 degrees for the monkey and between 25 degrees and 40 degrees for the chick. The magnitude of the threshold between these limits depends in large part on the effect of practice.

The training records, as well as the final results, suggest that difference in direction is a much more significant characteristic for the monkey than for the chicken.

The relative improvement brought about by training is very

* Communicated by the Director.

[1] To appear in the *Journal of Animal Behavior.*

much greater for the monkey than for the chicken. This fact suggests that in discrimination of this type other differential factors than relative development of the sense-organ play an important part. The point is emphasized by the fact that the monkey's visual acuity was demonstrated to be not over five times as good as that of the chicken, while his sensitivity to differences in direction is from eight to twelve times as great.

VISUAL PATTERN-DISCRIMINATION IN THE VERTEBRATES. A DEMONSTRATION OF THE DOG'S DEFICIENCY IN DETAIL-VISION.[1]

By H. M. Johnson.

SOME years ago the writer made some lengthy experiments [2] on the rate and methods of acquiring skill of blind, temporarily blind, and normal dogs, and accumulated quite a mass of evidence that in learning to make quite complicated adjustments the dog makes but little use of vision. There was also some evidence that in uncontrolled behavior dogs react to many ordinary objects as if the latter were not visually perceived. These data emphasized the interest of the question as to the kind and degree of vision which the dog may have.

In the year 1911–12 I attempted to train a dog by the discrimination-method of Yerkes and Watson to discriminate between a circle 6 cm. in diameter and its approximately equivalent square. In the preliminary training I presented a 4 to 1 difference in brightness (which in this case made a 4 to 1 difference in luminous intensity) in addition to the difference in outline of the two objects. Under these conditions the dog established discrimination in 1000 trials. When the two fields were equated in brightness he ceased to discriminate, and showed no preference for the positive field in 600 additional trials.

In the present work I used a pure-bred English bull-terrier with two emmetropic eyes. The first attempt made was to train him by the Yerkes-Watson method to choose a food-box indicated by a field covered by coarse stripes, and to avoid, under penalty of an electric shock, a food-box indicated by a field of uniform

[1] To appear in the *Journal of Animal Behavior*.

[2] Johnson, H. M.: "Audition and Habit-formation in the Dog," Behavior Monograph No. 8. Cambridge, Mass., Henry Holt & Company, 1913.

brightness. The two fields were, of course, interchangeable with reference to the food-boxes, and were equal in area, outline, and mean brightness, the latter being 12.2 candles per square metre. The animal was required to choose at a minimal distance between test-object and eye of 60 cm. He failed to learn the problem in 1200 trials, although the pattern on the "positive" field was quite coarse. A monkey and two chickens trained under comparable conditions established a perfect habit in from 200 trials to 400 trials each.

I then presented a difference in area in addition to the difference in distribution of brightness over the fields, and the animal acquired a perfect habit very quickly. Control tests showed that the difference in pattern was ineffective, as the animal's responses were not affected in accuracy by eliminating that difference. The effective difference in area was between 2.25 to 1 and 1.44 to 1. Since the two fields were of equal brightness, this difference in area resulted in a corresponding difference in luminous intensity. I now made the brightness of the test-fields inversely proportional to their areas, and the animal immediately ceased to discriminate. This indicated that his discrimination-habit had been based on difference of luminous intensity alone.

It now became necessary to ascertain and consider certain structural characteristics of the dog's eye considered as an optical system. There is a mechanism for accommodation as in the typical mammalian eye. According to Freytag, however, the refractive index of the lens is almost exactly the same as that of the fluid media. All the refraction undergone by an incident beam in such an eye must, therefore, take place at the cornea. Change of the radius of curvature of the lens would not in itself change the focal length. The eye is set for a single focal distance, and only objects at a given distance may be imaged on the retina. In this dog, parallel rays, or rays proceeding directly to the eye from an object 20 feet or more away, are brought to a focus on the retina. In the next experiment each test-object was mounted in the principal focus of a good projection lens. Under the experimental conditions a sharp image of the test-object was formed on the retina, no matter where the dog's eyes were placed in the cone emerging from the lens.

In this experiment the two fields were 6.2 candles per square metre in mean brightness, circular in form, and 6 cm. in diameter.

The positive field was covered by a system of alternate dark and bright stripes, each member of which subtended a visual angle of 33′ 32″. The negative field was of sensibly uniform brightness. The pattern on the positive field may be compared to that of a plank fence in which the planks are 6 inches wide and 6 inches apart, viewed at a distance of 50 feet. The dog did not learn to discriminate between these two fields and did not show a tendency to improve in 500 trials. Under the circumstances I regard his failure as conclusive evidence that he is unable to distinguish quite gross details in visual objects. Since the experimental conditions insured the formation of a sharp image on the retina, we must attribute his failure to relative insensitivity of that organ to distribution of brightnesses over it. There is no fovea in the dog's retina, the sensitive area is indefinite both in form and extent, and there are numerous branchings of opaque nerve-fibres which must be regarded as blind spots. As is suggested above, if accommodation is not impossible, its range must be extremely small. There is a tendency to gross errors of refraction, varying widely in different individuals. For many of them the retina can never be stimulated by a sharp image. It should not be inferred from the above that the dog's eye is a useless organ, for such a retina, like the peripheral region in the human retina, seems to be quite sensitive to movement of visual objects. This is probably the most important form of visual sensitivity which the dog possesses.

The structural characteristics of the dog's eye obtain among other carnivora and among ungulates and rodents. The foregoing results, considered in the light of comparative anatomy, suggest that we are not justified at present in attributing detail-vision to many other mammals below the primates.

THE FRANKLIN INSTITUTE

(Proceedings of the Stated Meeting held Wednesday, November 17, 1915.)

HALL OF THE FRANKLIN INSTITUTE,
PHILADELPHIA, November 17, 1915.

PRESIDENT WALTON CLARK *in the Chair.*

Additions to membership since last report, 8.

A report on the condition of the work of the Committee on Science and the Arts was presented.

Mr. G. H. Clamer, Chairman of the Committee on Science and the Arts, introduced Mr. Harold N. Anderson, of Cleveland, Ohio, and Mr. H. W. Hardinge, of New York City, to whom had been awarded the John Scott Legacy Medal and Premium by the City of Philadelphia on the recommendation of The Franklin Institute, the former for his Gear Rolling Machine and the latter for his Conical Pebble Mill. The medals were presented to Messrs. Anderson and Hardinge by the President.

A. A. Michelson, Ph.D., Sc.D., LL.D., Professor of Physics, Ryerson Physical Laboratory, University of Chicago, presented the paper of the evening, entitled "On the Ruling of Diffraction Gratings." The speaker reviewed the history of the ruling of gratings, and gave an account of the work of Rutherford, Rowland, and others. He pointed out the difficulties encountered in making gratings of large size and high resolving power, and described the devices employed for overcoming such difficulties, especially by the use of interference methods. Reference was also made to some of the modern problems requiring high resolving power. The subject was illustrated by lantern slides, specimens of gratings, and apparatus.

The Chairman requested Dr. Hoadley to preside during the discussion, in which Messrs. Saunders, Henderson, Levy, Bond and Drs. Goldsmith, Trowbridge, Barnes, Northrup, Goodspeed, and Ives participated. After a vote of thanks to the speaker the meeting adjourned.

R. B. OWENS,
Secretary.

COMMITTEE ON SCIENCE AND THE ARTS.

(Abstract of Proceedings of the Stated Meeting held Wednesday, November 3, 1915.)

HALL OF THE FRANKLIN INSTITUTE,
PHILADELPHIA, November 3, 1915.

DR. G. A. HOADLEY, *Chairman pro tem.*

The following reports were presented for first reading:

No. 2626.—Dorr's Hydrometallurgical Apparatus.

No. 2635.—Northrup's High Temperature Investigations.

The following report was presented for final action:

No. 2617.—Permutit. Final action on this report was deferred until next meeting.

The followinig report was presented for reconsideration:

No. 2636.—Lenker's L-E-Vation Rod. Reconsideration of this report was deferred until next meeting.

R. B. OWENS,
Secretary.

SECTIONS.

Section of Physics and Chemistry.—A joint meeting of the Section and of the Philadelphia Section of the American Chemical Society was held in the Hall of the Institute on Thursday, October 28, 1915, at 8 o'clock P.M., with Mr. C. C. Tutwiler in the chair. The minutes of the previous meeting were read and approved.

The presiding officer introduced Dr. Harlan S. Miner, chairman of the Philadelphia Section of the American Chemical Society, who then presented the speaker of the evening, Dr. Frank K. Cameron, of the Bureau of Soils, U. S. Department of Agriculture, Washington, D. C.

Dr. Cameron delivered an illustrated lecture on "The Development of a Dynamic Theory of Soil Fertility." The different static theories of soil fertility were reviewed, and the gradual evolution of the modern dynamic theory of soil fertility was traced. The various dynamic factors which influence the fertility of the soil were discussed. A vote of thanks was extended to Dr. Cameron, and his paper referred for publication. The meeting adjourned after an interesting and extended discussion.

JOSEPH S. HEPBURN,
Secretary.

Section of Physics and Chemistry.—A joint meeting of the Section and of the Philadelphia Section of the American Chemical Society was held in the Hall of the Institute on Thursday evening, November 4, 1915, at 8 o'clock, with Drs. Robert H. Bradbury and Harlan S. Miner, presidents of the two sections, presiding jointly. The minutes of the previous meeting were approved as read.

Charles H. Herty, Ph.D., Professor of Chemistry in the University of North Carolina and president of the American Chemical Society, delivered a lecture on the "Turpentine Industry in the Southern States." The old method of "boxing" the pine trees in order to collect the oleoresin, and the destruction of the forests as a consequence, were discussed. The new method of tapping the trees by means of troughs was described; the process is far less injurious to the trees, produces a greater yield of turpentine, and the rosin is of a higher grade. The present view of the physiology of the resin

secretion and flow was presented. The lecture was illustrated with lantern slides and with specimens of the tools used and products obtained in the turpentine industry. The paper was discussed by Drs. Herty, Harshberger, and Remington, Messrs. Stratton, Levy, and Benoliel and others. A vote of thanks was extended to the lecturer and the meeting adjourned.

JOSEPH S. HEPBURN,
Secretary.

Section of Physics and Chemistry.—A stated meeting of the Section was held in the Hall of the Institute on Thursday, November 11, 1915, at 8 o'clock P.M., with Dr. Gellert Alleman in the chair. The minutes of the previous meeting were approved as read.

Professor J. C. McLennan, Ph.D., F.R.S., Director of the Physical Laboratory of the University of Toronto, Canada, delivered a lecture on "Spectra, Their Origin and Some of their Characteristics." Series, resonance, fluorescence, and single-line spectra were described, as was the structure of the finest spectral lines. The best method for the production of metallic arcs was pointed out. The relationship between certain elements and their spectra, and the relationship between the quantum theory, spectra characteristics, and the structure of the atom, were discussed. The lecture was illustrated with lantern slides. After a discussion of the paper, a vote of thanks was extended to the lecturer, and the meeting adjourned.

JOSEPH S. HEPBURN,
Secretary.

A RELATION CONCERNING THE DISTRIBUTION OF AN ELECTROLYTE BETWEEN WATER AND SOME SECOND SOLVENT AND ITS DISSOCIATION CONSTANT IN AQUEOUS SOLUTION.

CORRECTION.

SWARTHMORE COLLEGE,
Swarthmore, Pennsylvania,
Department of Chemistry.

November 16, 1915.

The Editor,
JOURNAL OF THE FRANKLIN INSTITUTE.

DEAR SIR:

I have just had my attention called to an error in my paper on "A Relation Concerning the Distribution of an Electrolyte between Water and Some

Second Solvent, etc.," which appears in the July, 1915, issue of the JOURNAL OF THE INSTITUTE. Equation (21), page 68, should read:

$$z = \frac{c' - c\sqrt[2n]{\frac{b'}{b}}}{\sqrt[n]{\frac{b'}{b}} - \sqrt[2n]{\frac{b'}{b}}}$$

and not:

$$z = \frac{c' - c\sqrt[2n]{\frac{b'}{b}}}{\sqrt{\frac{b'}{b}} - \sqrt[2n]{\frac{b'}{b}}}$$

If this correction could be published in the December number of the JOURNAL, I should be obliged.

Yours very truly,

H. JERMAIN CREIGHTON.

MEMBERSHIP NOTES.

ELECTIONS TO MEMBERSHIP.

(Stated Meeting, Board of Managers, November 10, 1915.)

RESIDENT.

MR. ARTHUR COLLINS, Atlas Ball Company, Second Street and Glenwood Avenue, Philadelphia, Pa.

MR. RICHARD HOWSON, Southwark Foundry and Machine Company, 430 Washington Avenue, Philadelphia, Pa.

DR. ARTHUR WELLS YALE, 2008 Walnut Street, Philadelphia, Pa.

NON-RESIDENT.

MR. ROBERT JOHN ANDERSON, School of Mines and Metallurgy, University of Missouri, Rolla, Mo.

MR. EUGENE E. AYERS, Sharples Specialty Company, West Chester, Pa.

MR. CHESTER LICHTENBERG, 138 Park Place, Schenectady, N. Y.

MR. LEGRAND PARISH, American Arch Company, 30 Church Street, New York, N. Y.

MR. ARTHUR W. THOMPSON, Baltimore and Ohio Railroad Company, Baltimore, Md.

CHANGES OF ADDRESS.

Chief Constructor W. L. CAPPS, care of Bureau of Construction and Repairs, Navy Department, Washington, D. C.

MR. J. H. GRANBERY, 312 West Twentieth Street, New York, N. Y.

MR. JOHN J. KOHLER, Devitts Camp, Allenwood, Union County, Pa.

PROF. J. AMBROSE MOYER, Director of Extension Service, Massachusetts Board of Education, Boston, Mass.

MR. CHARLES S. VADNER, 22½ South Seventh Street, West, Salt Lake City, Utah.

MR. WILLIAM CHATTIN WETHERILL, Keystone Screw Company, care of Frishmuth Brothers & Co., Seventeenth Street and Lehigh Avenue, Philadelphia, Pa.

NECROLOGY.

William Hunter, Philadelphia, Pa.

LIBRARY NOTES.

PURCHASES.

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GREEN, ARTHUR G.—Analysis of Dyestuffs. 1915.

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CURRENT TOPICS.

Phonograph Styluses. J. B. TAYLOR. (*Scientific American*, vol. cxiii, No. 20, November 13, 1915.)—Many of the well-known disk records, a type which has supplanted the cylindrical form except for specialized uses, have a groove of uniform depth in which a needle or stylus of steel or other metal, or sometimes of fibrous material, rests. Here the sound record is traced by a lateral motion of the stylus in the plane of the disk. There are a large number of forms, types, and makes of needles on the market, and extravagant claims are made for many of them.

To secure a faithful transmission of the sound record to the diaphragm, it is essential that there shall be no lost motion in the cam-action between the needle point and the groove. For proper tone rendering, the stylus or needle must fit and fill the slot exactly: if too small, it will be thrown from side to side, giving false tones; if too big, it will give trouble by jamming and causing excessive wear of the record. The impracticability of making records and large numbers of jewels with grooves and points of duplicate and exact curvature and dimensions is practically met by using needles of steel or other material sufficiently soft to wear from an approximate to an exact fit in the first few revolutions of playing a piece, and yet sufficiently hard to play the whole of one or two records without wearing down to too extensive a shoulder bearing or too long a base bearing for satisfactory tone rendering. For best results it is obvious that steel needles should be used to play but one record and then be discarded.

"Permanent" or multiplying needles in general, for lateral cut records, should be regarded with suspicion and used with great caution, for, while there are types of needles which may not damage a record when used intelligently, the harder a needle and the less the wear, the greater the damage to the record if the needle is removed from the holder and replaced in a different position.

Possible Source of Potash. ANON. (*United States Geological Survey Press Bulletin*, No. 245, November, 1915.)—Following Secretary Lane's instructions to put special effort into its potash investigations, the United States Geological Survey is publishing the suggestion that a possible source of potash may exist in the tailings piled up at the concentrating mills of the big copper mines in the West. The "porphyry" ores which are being mined by the millions of tons annually contain several times as much potash as copper, and this remains in the tailings at the mills, material already finely ground and in condition for treatment, as well as easily accessible

for shipment. This potash, however, is locked up in the form of silicate minerals, and the commercial extraction of potash from silicates has been for several years the subject of earnest study by industrial chemists. If this problem can be solved, it would appear that a large tonnage of potash-bearing material is available in the Western States.

The brief report issued recently by the Geological Survey (Bulletin 620–J) contains typical analyses of these "porphyry" ores from the largest copper camps in a half-dozen States, as well as tonnage estimates of the ore reserves and ore already mined and treated. A few check analyses of tailings are also published.

Suggestion of a possible potash reserve in these tailings originated with B. S. Butler, the geologist in charge of the Survey statistical study of copper, who has based this short paper upon the published analyses of specimens collected by the government geologists in their investigations of the mining districts.

The significant fact regarding this possible source of potash is that in quantity it is more than adequate to meet all the needs of the country as measured by present consumption of potash. The problem of potash extraction from this by-product of the copper industry therefore becomes an attractive one for the chemical engineer and mineral technologist.

Evaporation of Potash Brines. ANON. (*United States Geological Survey Press Bulletin*, No. 244, November, 1915.)—In connection with the general potash investigations that have been carried on for several years by the United States Geological Survey, a number of desert basins in the West have been more or less thoroughly explored and many brines, saline residues, and muds have been analyzed with special reference to their content of potash. These investigations show that a few American brines contain rather high percentages of potassium, and that most brines contain it in appreciable quantity, although salts of sodium preponderate in all the brines examined. Economical methods for extracting the potash from American brines are now eagerly sought, but the work is still in the experimental stage. Fractional evaporation—a process by which brines are evaporated in stages and the deposited salts removed from time to time—is an essential part of what appears to be the most practical methods proposed, and detailed knowledge of the effects of evaporation on potash brines is therefore of paramount importance. Some experimental work to determine these effects has been done by W. B. Hicks, of the United States Geological Survey. Several different potash brines were subjected to fractional evaporation and the effect on the concentration of their constituents was determined by analysis. The results are published in a recent Survey publication—"Evaporation of Potash Brines"—issued as Professional Paper 95–E. This report shows that, in general, by evaporating the brines investigated the concentration of the potas-

sium is increased until the solution contains about 4 per cent. of potassium, and that on further evaporation the potassium salts are rapidly deposited from solution along with larger quantities of sodium salts. The paper is a preliminary report, and the data presented suggest the importance of a more extended investigation of American natural brines.

How the Efficiency Engineer Studies the Human Machine. ANON. (*Scientific American*, vol. cxiii, No. 19, November 6, 1915.)—A valuable application of the cinematograph has been found in its use for motion study. Mr. Frank B. Gilbreth, whose work in this field is well known, has substituted the moving-picture method of recording the motions made by the operative for the tedious pad, pencil, and stop-watch method previously employed. By using a clock and a microchronometer recording the thousandth part of a second and photographing them with the operations, the exact time and duration of the motions can be recorded. Having a perfect record of the path of motion and the time, a measure of the distance is obtained by performing the operations in a cross-sectioned table and before a cross-sectioned screen. A further improvement in this method has been effected by attaching a small electric lamp to the hand of the operation so that when the photograph is taken, the path of the hand will show as a line of light. When the motions of both hands are to be distinguished, interrupters are used in the lamp circuits producing different types of dotted lines that can be readily identified.

One of the chief drawbacks lies in the cost of the films, and it occurred to Mr. Gilbreth that it was not necessary to take photographs of the size commonly used for projection on a large screen. Accordingly he devised a type of shutter which can be placed directly before the film, so that only a portion of it will be exposed. By successively so exposing several portions of the film, it was found that four pictures can be taken in the space of one. The number of exposures has since been increased to eight, then sixteen, and finally to twenty-four, so that a single reel can do the service previously required by two dozen.

Olive Oil Manufacture in Palestine. O. A. GLAZEBROOK. (*United States Commerce Reports*, No. 272, November 19, 1915.)—All olive oil made in the Jerusalem consular district, whether by the older processes or by more modern machinery, is considered as edible without refining, with the sole exception of that last pressed from the bruised berries. This, being dark and containing much of the pulp, is fit only for the soap industry, and then only after being mixed with better qualities.

The old native oil presses consist of a circular stone trough elevated a little from the ground, in which a stone disk rotates around an upright shaft. This disk turns on its edge like a wheel, and is

operated by a horse, mule, or camel. One man is constantly stirring, removing, and replacing the olives as they are crushed, another man carrying the whole olives to the mill and returning with the crushed ones. Once sufficiently crushed, they are placed where they can be filled into circular baskets that have a small opening and are quite flat. These baskets have been in use for a long time.

The older extraction method, and one still much in use, calls for a wooden box for a mould, in which a large piece of coarse goat's-hair cloth is laid. The box is filled with the crushed berries, pressed compactly together, after which the cloth is folded over the top in a cater-cornered style. These are now ready for the press. This method of crushing the olives is the oldest known, possibly dating back hundreds of years, as ruins of mills would seem to indicate.

Modern mills using imported machinery, when without power, employ exactly such a crusher; when driven by a motor, as many now are, two smaller stone disks are used, both placed on the same axle. In all cases these stones are from the local native quarries.

With the primitive oil presses, there is built in one of the walls of the room a recess just large enough to admit the baskets of crushed berries and reaching to the ceiling, with a small cistern below to receive the oil. In the centre of the room is a mammoth wooden screw. A large beam extending across the room has one end entering the recess above mentioned, while in its centre lengthwise is a screw in which the larger one operates.

Once the olives are crushed and filled into baskets or hair-cloth, they are placed one upon another in the press recess, the screw is turned around and around by means of a stick of wood run through a hole for the purpose, and the gigantic beam descends, reducing the pile of baskets to half the height, while the oil runs in streams into the reservoir below. This press, being of insufficient strength, does not at once extract all the oil, so the pressed pulp is subjected to a second crushing and squeezing and then packed away in a corner of the room until the olive season is over. It is then ground for the third time and re-pressed.

These primitive devices, while they still exist, are rapidly falling into disuse, as they are too laborious and do not produce as much oil as the more modern ones.

The modern iron oil presses are either imported from France or are copies made by local machine shops. Those used where no power exists have the pressing screw operated by a long, large beam pulled by rope and tackle, while the newer types have presses operated by kerosene engines. With these metal presses but one squeezing is the rule, after which the pulp is subjected to a second crushing and pressing only for the dark soap oil. During the pressing process boiling water is poured on the pulp to make the oil separate more easily.

Since the natives are not at all particular about cleaning their mills, especially with the old type of press, the rancid oil from the

previous year soon impregnates the new. Besides this, the natives commonly collect their entire crop before beginning to press, piling the berries on the flat stone roofs of their houses. The olives thus lie in a heap, often for weeks, being left until the first winter rains descend upon them—all of which is thought to help ripen the olives and thereby to produce more oil. It possibly may do so with the primitive methods, but this heating of the fruit results in a sharp and rancid product, which taste, however, the natives do not seem to mind.

A few modern mills endeavor to produce a better table oil, which they sell at an advanced price. In these the berries are not allowed to heat, and are pressed soon after being picked. The oil is stored in metal tanks, which are scoured before using, as is all the machinery employed, very sweet and clear oil being thus obtained. Some even collect the oil that of itself flows away from the crushed berries before being pressed, which is considered very superior. No methods of filtering or refining are known. The oil is simply allowed to settle and cure itself; and, while it has a sharp taste when quite fresh, this taste is soon lost.

There was $3200 worth of olive oil shipped from this district to the United States in 1914, the invoices being certified at the Jaffa consular agency.

A Gaseous-conductor Lamp for Color Matching. D. McF. MOORE. (*Electrical World*, vol. 66, No. 21, November 20, 1915.)—At a joint meeting of the American Electrochemical Society and the Illuminating Engineering Society held at New York on November 11, Mr. Moore demonstrated his new carbon-dioxide vacuum tube lamp, which employs a new principle for automatically replenishing the supply of gas within the tube as the gas is used up in the operation of the lamp. Elaborate spectrophotometric investigations have been made to show that articles of various colors when viewed solely by the light of the new tube lamp have exactly the same shades of color which they display when viewed by the light from a clear sky.

The straight tube lamp is contained in an elongated sheet metal case which is provided with a screw base similar to that used on the larger sizes of incandescent lamps. Instead of feeding the lamp the CO_2 gas by means of an auto-magnetic feed valve, the gas is automatically generated within the tube itself. Near each electrode is placed a small bulb containing calcium carbonate, from which emanates the carbon dioxide when the resistance wires imbedded in it, connected in shunt to the gas column, become heated to the requisite degree. The gas column measures $\frac{7}{8}$ inch in diameter and 1 foot in length, and appears as a solid bar of light of intense whiteness. The foot-candles available near the tube are more than 200, making the apparatus suitable for the very closest color discriminations. The degree of vacuum is automatically held within 0.001

mm. of mercury, and the apparatus will withstand wide line-voltage fluctuations without becoming disarranged in any way.

A Novel Device for Preventing the Washing of Roads. H. G. SHIRLEY. (*Maryland State Roads Commission.*)—A novel and practical device is used in the State of Maryland to prevent the washing-out of road shoulders and gutters. These "breakers," as they are termed, answer their purpose so well that they will pay for themselves after two or three heavy storms. They are considerably cheaper than cobblestone gutters, give thorough protection to the shoulders of the road, and may be used on any type of highway, including farm lanes and driveways.

The breaker consists of a low concrete barrier extending from the edge of the road diagonally through the shoulder to the ditch. It is built flush with the surface of the road shoulder, and where the highways are patrolled and the shoulders kept in repair it is no objection to travel. Breakers are spaced as occasion may require, and are neither expensive nor difficult to build. The Maryland breakers are 12 inches wide and 18 inches deep. The spacing varies with the nature of the soil, grade, and amount of water they encounter. Thus it would probably be necessary to space them closer at the bottom of a hill than at the top. On 5 or 6 per cent. grades and medium soil they are spaced 25 to 30 feet apart. Where the soil is liable to wash and the grade is steeper they would be spaced much closer. The length as well as the grade of a hill would also influence spacing.

State Production of Quinine in Italy. W. F. KELLEY. (*United States Commerce Reports*, No. 271, November 18, 1915.)—For several years past the Italian Government has operated laboratories for the production of quinine for medicinal purposes, especially for use against malaria and other fevers. The Director General of the "Regie" has recently published a report upon the State quinine production during the fiscal year ended June 30, 1914, and it is from this report that the following data are taken:

The total receipts from this industry in the year under review were $611,283, and expenditures, $451,304, showing a net profit of $159,979, a sum considerably less than that realized during the preceding year, chiefly owing to the increased cost of the raw materials. The whole of this profit was devoted to scientific investigation, drainage of unhealthful districts, free distribution of quinine, and other preventive and curative measures against malaria.

The total sales of prepared quinine in the fiscal year 1913–14 amounted to 80,782 pounds, an increase of 1891 pounds over the preceding year. A smaller demand from Greece and Bulgaria caused a falling off in total exports.

The average consumption in all Italy per 1000 inhabitants was 10,077 grains in the year under review, an increase of 1296 grains. The province of Foggia, in southeastern Italy, showed the largest

consumption (44,198 grains per 1000 population), and the province of Carrara the smallest (77 grains per 1000). In the province of Rome the consumption was 22,547 grains; in Milan, 6960 grains; Turin, 6019 grains; and Naples, 3349 grains per 1000 population.

The largest quinine laboratories are at Turin, but the rapid growth of the demand for this product has necessitated the establishment of laboratories in Rome and other parts of the kingdom as well.

Electric Propulsion for a Battleship. W. L. R. EMMET. (*Proceedings of the Society of Naval Architects and Marine Engineers,* November 18 and 19, 1915.)—The Navy Department of the United States has awarded to the General Electric Company of Schenectady, N. Y., a contract for the electric propelling machinery for the new battleship *California,* which is being built at the New York Navy Yard. This ship is of the largest and most powerful class which has been adopted by the United States. Her displacement is 32,000 tons and her maximum speed is to be about 22 knots, requiring about 37,000 shaft horse-power. The contract covers two turbine-driven generating units, four propelling motors (one on each shaft), switching apparatus, cables, instruments, etc., and two turbine-driven exciting units, and a complete equipment of condensing auxiliaries and ventilating blowers, all driven by motors from the exciting units. In fact, it covers practically the entire engine-room equipment except the main condensers.

Each of the auxiliary units is of 300 kilowatts capacity, with a 240-volt direct-current generator geared to a high-speed non-condensing turbine. These turbines will exhaust into the heaters, into the main turbines, or both.

The motors which drive the auxiliaries will be designed for a considerable range of speed variation, so that the auxiliaries will be adopted to economical conditions at different speeds of the ship.

The award of this contract was the result of a very long campaign of education which has been conducted by the writer in which the equipment of the collier *Jupiter* has been an incident. The writer has from the first maintained that the proper field for electric propulsion was in ships of high power and in ships when economy at widely-varying speeds was important. The *Jupiter* has now been in commission for two years and has proved an unqualified success. The steam consumption of the main drive with 190 pounds pressure, dry steam, and 28.5 inches vacuum is 11 pounds per horse-power hour delivered to the propeller shafts, which is at least 30 per cent. better than is done by reciprocating engines in ships of the class. There is also evidence of further saving in the *Jupiter,* incident of the fact that her large low-speed propellers are turned with a perfectly uniform angular motion and with entire freedom from racing, conditions heretofore unknown with such propellers.

The generators of the *California* are bipolar alternators, and the

motors are arranged to be connected either for 24 poles or 36 poles. For economic cruising at 15 knots or less, one generator will be used with motors on 36-pole connection; for higher speeds the 24-pole connection will be used. The ship will be capable of operating at a speed of 18.5 knots with one generator. Speed variation with each motor connection will be effected by change of turbine speeds through the agency of variable speed governors designed to hold automatically any desired speed within the usual ranges. This arrangement, which is also in the *Jupiter*, entirely prevents racing and makes it convenient to hold a fixed speed, irrespective of variation in sea, weather, or steam conditions. It is thought that this feature will be valuable in fleet formations.

The steam consumption guaranteed on the *California* covers the total steam required for the main turbines and the engine-room auxiliaries as described above. The conditions are 250 pounds gauge pressure, dry steam, with such vacuum as can be produced under trial conditions. The guaranteed water rates per horse-power delivered to the propeller shafts are: at 10 knots, 14.6 pounds; at 15 knots, 11.4 pounds; at 19 knots, 11.1 pounds, and at maximum speed, 11.9 pounds—a gain in propeller efficiency of 9 per cent. over other vessels of the same class equipped with the usual arrangement of turbine engines.

Better Bread by Means of Natural Lactic Acid. A. WAHL. (*The Journal of Industrial and Engineering Chemistry*, vol. vii, No. 9, September, 1915.)—(1) The general appearance of a loaf of bread is greatly improved by the use of bacterial lactic acid; a larger loaf results per weight of bread, with improved bloom and color of crust. (2) Through the chemical influences of the bacterial acidity there results a greater whiteness of crumb, with improved texture, consisting of a more uniform distribution of the fermentation gas cells, which are in smaller size in augmented number. (3) A finer flavor and increased palatableness are imparted by a chemical combination with the phosphates of the flour. (4) By using bacterial lactic acid produced by propagating *Bacillus Delbruecki* in a bran mash, all the highly nutratitious extractive substances of the bran are thus incorporated into the dough, while the lactic acid renders soluble the proteins and basic phosphates of the flour, which results in a more wholesome product by reason of its increased digestibility. (5) Undesirable microörganisms are checked. (6) Peptase and diastase are released, effecting a partial digestion of the dough, the resulting soluble proteins, phosphates, and carbohydrates serving as a most desirable nourishment for the yeast. (7) Milk, whey, buttermilk, and similar milk products containing either added or developed bacterial lactic acid, when added to the dough, also effect a similar improvement in the bread. (7) Commercial lactic acid may be used with improved results, but bacterial acid is preferable, and that bacterial lactic acid which

is produced by the organism *Bacillus Delbruecki* is the most desirable, since this lactic acid, with the extractive substances in it, contains a much greater concentration of hydrogen ions upon which the effectiveness of this acid largely depends.

Safeguarding Roads in Winter. ANON. (*Office of Information, United States Department of Agriculture*, October, 1915.)—Water, not cold, is the cause of the deterioration of roads in winter, according to the road specialists of the United States Department of Agriculture. Cold weather does not in itself injure roads, no matter whether they are earth, gravel, or macadam. In fact, an earth road will bear more traffic when it is solidly frozen than at any other time. Excess water, however, is always detrimental to a highway. When cold weather turns this water into ice, the damage that it does is greatly increased.

The action which takes place when a wet road freezes to any considerable depth is similar to that which occurs when water is frozen in a closed vessel. It simply bursts or, as it is generally termed in road parlance, the road heaves. Later, when the frost leaves, the road is disintegrated and ruts badly. If this process is repeated a number of times during the winter, a gravel or macadam road may be practically destroyed, while an earth road may become entirely impassable.

The remedy is obvious: the road should be kept free of water. The time to begin preventive measures is early in the fall, before the rains begin. If the road goes into the winter thoroughly dry, with the surface and drainage in good condition, the chances are extremely favorable that it will be found intact the following spring.

The Use of Ammonium Hydroxide for the Extraction of Rosin from Wood. H. K. BENSON and H. N. CRITES. (*The Journal of Industrial and Engineering Chemistry*, vol. 7, No. 11, November, 1915).—The extraction of rosin from "light wood" in the Southern States is accomplished by first steaming the chips, next covering them with a petroleum distillate, reheating until the distillate begins to vaporize, and then withdrawing the solution of rosin. By subjecting this solution to re-distillation the solvent is recovered first, and finally the turpentine and pine oil, leaving the rosin as residue. The main difficulty with this method is the loss of the solvent in the cycle, which, according to operators, is as high as 50 gallons per cord of wood treated. Recently the use of alkalies, such as caustic soda or soda ash, has been sugggested for the extraction of rosin. The difficulty of this method lies in the form in which the rosin is finally recovered, *i.e.*, as soap, for which apparently no great demand exists as obtained from wood by this process. The present investigation is based upon (1) the instability of ammonium salts when heated and (2) the completeness of the recovery of ammonia as commercially carried on in the coal-gas plants in this country.

Powdered rosin was added to a 25 per cent. solution of warm ammonium hydroxide, forming a thick, light yellow, transparent solution which became quite firm on cooling. It slowly decomposed while standing in the air, and on adding heat the ammonium was driven off, leaving rosin as a residue. The experiments indicate that when wood is treated with a 5 per cent. solution of ammonium hydroxide, equal to eight times the weight of the wood, at 70° C. for five hours, nearly complete extraction of the rosin occurs, and from the general properties of ammonia and its complete recovery in gas works nearly complete extraction of rosin from wood may be made and the ammonia completely recovered.

A New Peat-Distillation Process. C. A. HOLDER. (*United States Commerce Reports*, No. 272, November 19, 1915.)—A new process of distillation of peat has recently been patented in Great Britain and other countries by which coke, fuel oil, toluol, ammonia, paraffin wax, and acetone are obtained in sufficient quantities and of such high grade as to prove of great value. The process has been in practical operation now some six months and seems to promise to revolutionize the peat industry and to furnish sources of fuel oil to the British Navy which may possibly make it independent of foreign oils.

Peat, as taken from the peat beds, contains from 80 to 90 per cent. of water, and is of a fibrous cellular structure, so that by hydraulic pressure it is possible to lower the water content only slightly. An important part of the new process is a macerator that breaks up the fibrous cellular tissue and thus allows a more complete separation of the water. After passing through the macerator the broken peat is compressed into briquettes, which are dried until they contain not more than 25 per cent. of moisture, and then fed into a hopper, from which they pass into the retort.

The retort, though very simple, is the basis of the patent. It contains several chambers where different degrees of heat are applied. In the first a temperature of 300° C. (572° F.) is used for driving out the moisture remaining in the peat. In the next chamber the temperature is about 450° C. (842° F.), and here decomposition of the peat takes place. In the last chambers the temperature runs up to 600 or 800° C. (1112 to 1472° F.), and the oil and water are volatilized. By means of a worm screw, briquetted peat is passed in at one end of the retort and peat charcoal is discharged continuously at the other end, while from the various chambers the oil, water, ammonia, etc., are drawn off in the form of vapor and removed from longer contact with the heat.

After leaving the chambers the vapors pass through a condensing system which is so arranged that the heavy oil collects at one place, and the water and light oil in the form of vapor, together with some combustible gases, collect in another place. The combustible gases are separated from the water and oil and are utilized in keeping up the temperature of the retort, after it has obtained

its initial heat from coal, and they are ordinarily sufficient to carry on the subsequent processes without the addition of any further coal.

The coke obtained by this process contains 92 per cent. carbon, 1 per cent. moisture, 1.3 per cent. volatile matter, and 5.7 per cent. ash, and is very hard. It can be left with a larger percentage of moisture, and in this way, since it is softer, it can be used as fuel for domestic purposes. Its chief value, however, is in the manufacture of steel, owing to its wonderful hardness and the high percentage of carbon contained. Various steel makers have certified to its great value for this purpose. From a ton of peat nearly one-third of a ton of coke, valued at $6.08 to $7.30, is obtained.

The oil promises to be particularly useful as a fuel because of its low sulphur content. An examination of the oil showed it to be a most satisfactory substitute for petroleum. The amount of ammonia obtained per ton of peat is estimated at 20 pounds, with a value of two cents or more per pound. Both the oil and the ammonia contain water, but this is readily removed by the application of heat. In addition to these products, about 20 pounds of paraffin wax, valued at six or eight cents per pound, is obtained, and toluol and acetone; the quantity and value of the latter have not yet been ascertained. The paraffin wax is of good quality and can be employed for candle making and other purposes.

With peat costing about $1.95 per ton delivered in the hopper, dry, it is believed that by this process a profit of not less than $3.65 or $4.87 per ton will be obtained; and this does not include any allowance for the toluol and acetone, which may prove to be more valuable than all the other products together.

Peat from different localities gives different results, some peat containing larger amounts of volatile matter than others, and some peat having a low nitrogen content, while in others it is high. The yield of oil from English peat (Yorkshire) was 26.5 gallons per ton. By varying the conditions of distillation light or heavy oils may be produced as desired. The yield of oil, gas and ammonium sulphate can be controlled by regulating the length of time or the degree of heat to which the peat is subjected in the retort.

Of the many attempts that have been made to utilize peat this method is said by many experts to promise most.

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